Caltrans Transportation Management System Master Plan

financial plan report

prepared for

California Department of Transportation

prepared by

Cambridge Systematics, Inc.

In association with

System Metrics Group

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Table of Contents

Table of Contents
(continued)

List of Tables

List of Tables
(continued)

List of Figures

1.0 Background

Entering the 21st century, California's transportation system has matured; it only expands its transportation infrastructure by a fraction of a percentage each year. Yet, the fact remains that congestion is growing in the urban regions almost five times as fast as the population. Californians experienced double the congestion in Year 2000 compared to 1990; and the state expects another doubling this decade unless it manages to improve the productivity of our transportation system. Transportation Management Systems (TMS) are operational investments that modify the current transportation infrastructure to improve performance.

Over the last decade, the California Department of Transportation (Caltrans) has invested significant resources in TMS technology to help manage the state transportation system. TMS strategies deployed in the state include Incident Management (IM), arterial signal management, Traveler Information (TI) systems, and Ramp Metering (RM). These TMS are critical business processes and associated tools, field elements, and communication systems that help maximize the efficiency and safety of the transportation system, and enhance the productivity of our transportation system.

Caltrans is committed to integrating all prior and future TMS investments into a comprehensive plan that delineates the roles and responsibilities of different transportation agencies and stakeholders, identifies the goals and objectives of the overall transportation operations strategy, and lays out a detailed action plan to reach these goals. The overall operations strategy for the state is described in the Transportation Operations Strategy (TOPS) report published in February 2000. The TMS Master Plan is designed to build on the TOPS findings to define the necessary steps to fully enable the strategies discussed in the report.

The TMS Master Plan lays out the blueprint for safer and more effective operations of the state transportation system, through system management enabled by intelligent infrastructure. It is intended to be the foundation for all future Feasibility Study Reports (FSR), by laying out the critical milestones for harnessing information technology for system management. Moreover, the TMS Master Plan will guide Caltrans as it works with others to realize the vision that "California has the safest, best managed seamless transportation system in the world."

The Master Plan consists of six components as follows:

1. **Master Plan –** which outlines the policy direction for the entire Master Planning effort and integrates all findings and conclusions into a blueprint for implementation.

2. **Business Process Review –** which examines the "as is" business processes related to transportation management, especially as they relate to transportation management centers (TMCs) and related transportation management systems.

3. **System Management Business Plans –** which addresses components of system management separately and presents a specific plan for each element including incident management, arterial signal management, traveler information, and ramp metering.

4. **Performance Measurement Framework –** which presents performance measures for each of the business plans and a methodology for collecting the required data, computing measures, and reporting them periodically.

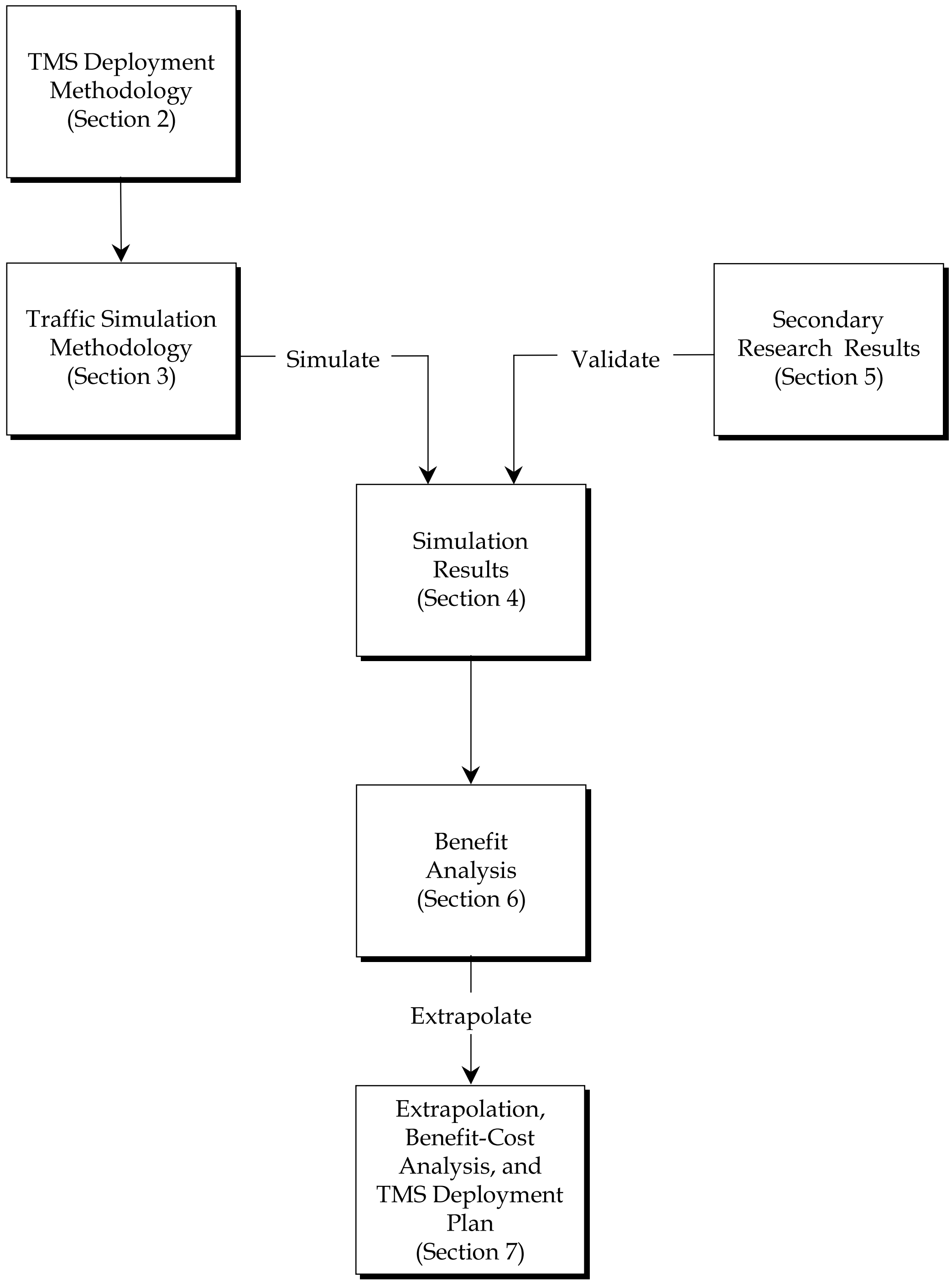
5. **Financial Plan –** which presents a TMS deployment methodology, an analytical framework to estimate the benefits and costs of existing and planned TMS projects and infrastructure, a benefit/cost analysis based on micro-simulation of two California corridors, and a prioritization plan for the deployment, operations and maintenance of TMS.

6. **Standardization Plan –** which identifies the processes, systems and applications that should be standardized across the state, and describes the framework for such standardization to achieve consistency and efficiencies during the implementation plan.

This report represents the *fifth* component of the Master Plan, the **TMS Financial Plan,** developed by Cambridge Systematics (CS) in association with System Metrics Group (SMG). Figure 1.1 provides a high-level overview of the process used to accomplish the study objectives. This report is organized as follows:

- **TMS Deployment Methodology (Section 2.0) –** Describes the statewide methodology for deploying TMS elements in California;
- **Traffic Simulation Methodology (Section 3.0) –** Describes the methodology used to identify the potential impacts and benefits resulting from the deployment of the TMS elements, using the guidelines presented in the previous section;
- **Simulation Results (Section 4.0) –** Discusses the results of the micro-simulation of the TMS field elements;
- **Secondary Research Results (Section 5.0) –** Validates the results of the micro-simulation by comparing simulated performance measures against results from various field evaluations;
- **Benefit Analysis (Section 6.0) –** Details the benefit analysis of existing and planned TMS elements in California; and
- **Extrapolation, Benefit-Cost Analysis, and TMS Deployment Plan (Section 7.0) –** Discusses the extrapolation methodology, provides estimates of California-wide impacts, and presents the benefit-cost analysis results; and presents a plan for TMS deployment in California.

Figure 1.1 Overview of the TMS Financial Plan Development Process



2.0 TMS Deployment Methodology

This section describes a methodology for deploying TMS field elements in California. The objective of the deployment methodology is to provide a basis for estimating the types, locations, and number of TMS field elements to be deployed in the future. TMS deployment methodologies were developed for four TMS business processes, including:

1. Incident management;
2. Arterial signal management;
3. Traveler information; and
4. Ramp metering.

Representatives from various Caltrans districts have contributed to the development of the guidelines, including Districts 3, 4, 5, 6, 7, 8, 11, and 12, as well as Headquarters. Additional agencies, such as the Federal Highway Administration (FHWA), San Diego Association of Governments (SANDAG), Michigan Department of Transportation (DOT), Oregon DOT, Minnesota DOT, and Arizona DOT were contacted by the project team to provide input on their own guidelines and experience as supplements to developing the California-based guidelines.

This document is intended to serve as a guideline for the conditions under which typical TMS field elements should be deployed in California. In many cases, field elements may serve more than one of the aforementioned TMS processes. For instance, detection field elements (e.g., loops, radar, video) may serve ramp metering, incident management, or traveler information systems. However, in most cases, the field elements are deployed initially for one specific process. For example, loop detectors are often installed near the ramps to enable advanced ramp metering. Once installed, however, the same data gathered and communicated by these loops can also be used for incident management and traveler information purposes.

As such, the criteria presented in this report identify the primary reason for deploying specific field elements. Caltrans districts have the flexibility to deploy field elements for other reasons when appropriate. For instance, video cameras are generally deployed for incident verification purposes. In some cases though, a district may deploy video cameras for traveler information purposes. The following sections present the deployment methodology for each category of field elements by business process. Detection field elements are discussed separately in Section 2.1, as detection is an enabling component for most TMS processes. Section 2.6 presents a summary of TMS deployment guidelines.

2.1 Vehicle Detection Field Elements

Vehicle detection field elements are fixed detection sensors placed in or along the roadway to detect vehicles and traffic conditions. They serve as the "eyes and ears" of the transportation operations staff and traffic management centers (TMC). According to the San Diego Association of Governments (SANDAG), detection mechanisms may include inductive loop detectors, radar, video detection, or other potential sensing devices. Table 2.1 summarizes the recommended vehicle detection deployment methodology for all types of detection mechanisms.

For freeways, the methodology is primarily based on the need to capture accurate speed and volume data, which are pre-requisites for the implementation of advanced ramp metering, incident management, and traveler information. For arterials, the methodology is primarily based on the need to capture speed and volume data at and between signalized intersections, which are pre-requisites for advanced arterial management strategies. Finally, on rural highways, detection is generally deployed for incident detection and traveler information purposes.

The deployment methodology for vehicle detection is based in part on studies by Caltrans, SANDAG, Michigan DOT and Oregon DOT. In its July 2000 *Traffic Monitoring Stations: Volume 1* report, SANDAG recommended deployment of loop detectors every one-half mile or less on urban/suburban freeways and highways. Beyond this frequency, detection would not be accurate enough in monitoring changes in traffic volumes, speed, or presence of incidents. SANDAG also recommended arterial detection to be deployed at all approaches of signalized intersections, and at mid-blocks where adaptive signal control is required.

Table 2.1 Recommended Vehicle Detection Deployment Methodology

Vehicle Detection
• **Urban/Suburban Freeways –** At least one detector station per urban freeway segment or ramp, or every one-half mile of urban/suburban freeway with detectors in each lane of mainline. Other deployment considerations include near lane configuration changes, and at locations with special vehicle mixes. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80.
• **Rural Highways –** At severe weather regions, segments with special vehicle mixes, and at key points along tourist routes with high-recurring congestion and/or weekend/seasonal congestion. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80.
• **Arterials –** At all approaches of signalized intersections and mid-block between signalized intersections where adaptive signal control is required.

■ 2.2 Incident Management Field Elements

Incident Management can generally be segmented into several phases: incident detection, verification and response, and clearance, as well as ancillary traffic management during/after an incident. Currently, incident detection is performed to a large extent by travelers using cellular telephones to call the California Highway Patrol (CHP) to report incidents. Remote incident verification may be enhanced through the use of video detection, such as closed-circuit television (CCTV), where available. Otherwise, it relies primarily on the CHP or Freeway Service Patrol (FSP) staff dispatched to the site to verify the reported incident.

Incident detection and verification are often greatly enhanced by video surveillance. Agencies have recognized this benefit and more than 1,000 CCTVs are currently deployed in California. Current CCTV technology with pan and tilt units has a zoom range of approximately 0.5 mile in each direction (Caltrans June 2001 Baseline Inventory Report). Therefore, if CCTVs are deployed one mile apart, they can be theoretically used to view the entire system. Geometric, geographic, and atmospheric conditions in some locations limit the range of the cameras, however.

Cameras should be deployed first at high-delay highway segments, at strategic interchanges, at interchanges with metered ramps/connectors, and eventually are intended to fully cover all urban freeways. Urban/suburban corridors would demand more attention, but rural areas with high weekend or seasonal congestion could benefit from CCTV coverage as well. The logic behind these guidelines is that most incidents/ accidents occur at high-volume, high-congestion locations and, thus, CCTV is most effective at these locations. The summary of the recommended deployment methodology for CCTV is presented in Table 2.2.

Table 2.2 CCTV Deployment Methodology

Closed Circuit TV
• **Urban/Suburban Freeways –** Maximum of one camera for every one mile of urban/suburban freeway, except where geographic, geometric or weather conditions require additional coverage. Other deployment considerations include near lane configuration changes and at locations with special vehicle mixes. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80. • **Rural Highways –** At severe weather regions, segments with special vehicle mixes and at key points along routes with high-recurring congestion and/or weekend/seasonal congestion. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80.

Note that once deployed, CCTVs are one of the most attractive sources for traveler information services. In fact, at times, special cases may warrant the deployment of CCTVs for traveler information purposes only. These special circumstances should be addressed on a case-by-case basis. Also note that changeable message signs (CMS) are often used during incidents to alert travelers of upcoming queues or slow traffic. However, the CMS field elements are discussed under the Traveler Information section, since they are also used for situations not related to incidents (e.g., weather, alternate routes).

2.3 Arterial Signal Management Field Elements

Arterial signal management strategies utilize advanced traffic signal controllers to coordinate intersection traffic signals along major corridors to improve mobility and operational efficiency. Furthermore, technological advances have allowed certain vehicles retrofitted with special equipment to communicate with the signal controllers to extend green time in their favor. For example, emergency or transit vehicles can use the signal preemption or signal priority features to improve their service times. According to the Michigan DOT *ITS Pre-Deployment Philosophy Study* developed in 2001, preemption for emergency vehicles should be provided at all intersections near hospitals, firehouses, and police stations.

This section presents proposed deployment methodologies for two types of arterial management field elements including: 1) traffic signal coordination elements and 2) traffic signal preemption/priority elements. The latter provides the capability to implement both emergency vehicle and transit vehicle preemption/priority strategies. The associated strategies are discussed in the following subsections and summarized in Table 2.3.

Table 2.3 Arterial Signal Management Deployment Methodology

Field Element	Arterial Signal Management Elements
Traffic Signal Controllers	**Urban/Suburban Arterials –** One per traffic signal connected to detectors at signal and mid-block. Priority should be given to arterial segments with forecasted volume/capacity greater than 0.75, consistent with traffic signal warrants in the Caltrans Traffic Manual.
Signal Preemption/Priority Elements	**Urban/Suburban/Rural Arterials –** One per traffic signal controller at intersections with: • High emergency vehicle traffic • Near firehouses, police stations, hospitals • High bus transit vehicle traffic • Dense population/Central Business District (CBD) • Long cycle lengths

2.3.1 Traffic Signal Coordination

Available traffic signal coordination techniques vary from simple, fixed-time signal systems with coordinated offsets to provide green time "bands" in favor of a peak direction, to the fully traffic-adaptive systems that let signal controllers communicate with one another and adapt to changing traffic conditions. In the future, Caltrans and most city agencies are expected to move toward deploying adaptive traffic signal systems, especially at thoroughfares that function as alternate routes to the freeways. Caltrans hopes to integrate the coordinated arterial signal systems with incident management and ramp metering, resulting in synergistic benefits of having multiple TMS components working together.

According to the FHWA's 2001, *Highway Economic Requirements System (HERS) in Operations Study*, the recommended minimum volume-to-capacity ratio to warrant traffic signal coordination is 0.75. Below this threshold, the system in question can still perform adequately with simpler, more cost-effective isolated signal controllers. Area population density is another factor determining the signal control type to be deployed (more populous areas warrant technologically advanced signal coordination); thus, urban and suburban area traffic signals under Caltrans control should be coordinated. Predictability of traffic demand is also another factor that should be considered, since locations with significant variation in traffic volumes (i.e., intersections near stadiums) are better suited for adaptive signal deployment.

2.3.2 Emergency Vehicle Signal Preemption

Emergency vehicle signal preemption is installed at signalized intersections that experience heavy emergency vehicle traffic, such as near firehouses, hospitals, and police stations, or at intersections with potentially long wait times due to long traffic signal cycle lengths. Area type generally plays a lesser role in determining preemption deployments, since even the most rural areas have their emergency services. Michigan DOT in its *Michigan ITS Pre-Deployment Study: Deployment Philosophy* recommends assigning deployment priority of signal preemption to Central Business Districts (CBDs) and densely populated areas, since these neighborhoods would carry more vehicular and pedestrian traffic. Studies have shown that preemption not only decreases travel time for the emergency vehicles, but would also reduce the probability of a crash at the intersections, while en route to the emergency site.

2.3.3 Transit Signal Priority

Similar to the deployment methodology for emergency vehicle signal preemption, transit signal priority systems are typically deployed at intersections with heavy transit activity. Again, area designations do not play a large role in deployment selections, although special attention should be placed to CBDs and areas with higher population density, at intersections near transit stations or transfer locations, and at intersections with long traffic signal cycle lengths.

2.4 Traveler Information Field Elements

Cooperation is required between public agencies that provide accurate traveler information and public or private entities that disseminate that information. This section focuses on two particular traveler information field elements that are used to communicate to the public – CMS and Highway Advisory Radio (HAR). Like incident management, traveler information relies on an extensive network of vehicle detection sensors linked to a TMC that controls the interpretation and dissemination of the data. Table 2.4 presents the summary of Caltrans' traveler information deployment methodology, which is also described in detail in the following subsections.

The information presented here is generally intended to guide the permanent or semi-permanent deployment of field elements. Both CMS and HAR technologies may also be used in mobile, temporary deployments, however, to provide information to travelers during construction or emergency situations.

Table 2.4 Traveler Information Deployment Methodology

Field Element	Traveler Information
CMS	• **Urban/suburban –** Upstream of major freeway-to-freeway interchanges and choke points. • **Rural –** At severe weather regions or upstream of major decision points.
HAR	• **Urban/suburban/rural –** When complex messages are needed to reach the travelers, such as at construction zones and severe weather regions.

2.4.1 Changeable Message Signs

CMS are normally placed upstream of major interchanges, allowing motorists to make routing decisions in the case of traffic congestion or a traffic incident further downstream. As a general rule, it is recommended that in urban or suburban areas, CMS are deployed upstream of major freeway-to-freeway interchanges and prior to bottlenecks. CMS deployments may also be located to provide destination-specific information to travelers heading to major airports, tourist destinations, or special events centers.

In rural areas, projects such as the California-Oregon Advanced Transportation System (COATS) developed by both Oregon DOT and Caltrans, recommend providing weather and traveler information in rural areas by adding CMS prior to major route decision points and in areas with severe weather conditions.

2.4.2 Highway Advisory Radio

HAR is used to broadcast traffic and weather information over the radio. Its information is not interactive and cannot be used to provide motorists with ad-hoc traffic information for specific locations. Both HERS and Michigan DOT suggest that HAR is a departing system that can be effectively substituted by CMS. However, HAR can be cost-effective when disseminating complex, detailed messages, such as warnings about construction zones and severe weather regions.

2.5 Ramp Metering Field Elements

Ramp metering is one of the most common urban congestion management techniques in use today. Ramp meters are used to control the entry of vehicles into the freeway, with the ultimate goal of maintaining safe and smooth freeway operations. The following are four basic types of ramp metering:

1. **Fixed-Time Ramp Metering –** This type of ramp metering imposes an equal amount of delay to each vehicle at the on-ramp when the meters are in operation – regardless of traffic conditions on the freeway mainline or at the adjacent arterial. Meters are typically turned on and off at scheduled times, and are usually not sensitive to actual levels of traffic. This type of ramp metering requires only loop detectors prior to each meter to detect the presence of vehicles on the on-ramp.

2. **Simple Adaptive Ramp Metering –** This type of ramp control can adjust its metering strategy based on the mainline traffic conditions upstream of the on-ramp. When the freeway mainline traffic is light, metering rates can be increased to allow more vehicles to enter the freeway. Conversely, the meters would increasingly restrict vehicles from entering the freeway if the detectors sense heavy traffic on the freeway mainline.

3. **Corridor Adaptive Ramp Metering –** This type of ramp metering works similar to the simple adaptive controllers, but also takes into account mainline traffic levels downstream of the on-ramp location. Some variants of this strategy allow ramp controllers to communicate with each other before deciding on metering rates. Such strategies are geared to optimize corridor performance, minimize travel time and traffic delay, and maximize throughput at freeway bottlenecks.

4. **Systemwide (Corridor and Arterial) Adaptive Ramp Metering –** This advanced metering strategy aims to go a step further by integrating both the freeway mainline and the arterials as one system. Metering rates are chosen to optimize systemwide performance. While holding a great promise and potential, systemwide control is still a nascent technology, and there is no current application of this strategy.

In each of these strategies, ramp Queue Control (QC) can be added, so on-ramp queues can be prevented from congesting local arterials and intersections. To do so, a set of detectors must be placed at the beginning of the on-ramp to sense idle vehicles, which in turn sends a signal to the controller to "flush out" the queue by temporarily raising the meter discharge rate.

In California, all forms of ramp metering deployments are limited to urban and suburban areas, with higher priority given to freeway segments with significant merging problems. Arizona DOT defines the sum of the traffic volume on the right-most lane in the freeway mainline and the on-ramp traffic volume must be at least 1,800 vph to warrant ramp metering (*Minnesota DOT, Twin Cities Ramp Meter Evaluation, 2001*).

Per current Caltrans policy, metered ramps have high-occupancy vehicle (HOV) meter-bypass lanes along freeways with HOV lanes. For the future, Caltrans and other state DOTs are moving towards adaptive metering control, taking into account the current and projected congestion levels at most of California's urban/suburban areas. The summary of the deployment methodology for ramp metering field elements is shown in Table 2.5.

Table 2.5 Ramp Metering Deployment Methodology

Ramp Metering
Urban/suburban – Where forecasted volume is greater than 1,800 vehicles per hour at the rightmost freeway lane plus on-ramp, and at areas with significant merging problems (Forecasted volumes are generally obtained from regional travel demand models.). Priority should be given to already congested locations whenever possible in coordination with regional and local jurisdictions.

2.6 Summary

Table 2.6 presents a summary of TMS field element deployment guidelines.

Table 2.6 Summary of TMS Field Element Deployment Guidelines

Field Element	Deployment Guideline
Vehicle Detection	**Urban/Suburban Freeways –** At least one detector station per urban freeway segment or ramp, or every one-half mile of urban/suburban freeway with detectors in each lane of mainline. Other deployment considerations include near lane configuration changes, and at locations with special vehicle mixes. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80.
	Rural Highways – At severe weather regions, segments with special vehicle mixes, and at key points along tourist routes with high-recurring congestion and/or weekend/ seasonal congestion. Priority should be given to interchanges with forecasted volume/ capacity greater than 0.80.
	Arterials – At all approaches of signalized intersections and mid-block between signalized intersections where adaptive signal control is required.
CCTV	**Urban/Suburban Freeways –** Maximum of one camera for every one mile of urban/ suburban freeway, except where geographic, geometric or weather conditions require additional coverage. Other deployment considerations include near lane configuration changes and at locations with special vehicle mixes. Priority should be given to interchanges with forecasted volume/ capacity greater than 0.80.
	Rural Highways – At severe weather regions, segments with special vehicle mixes and at key points along routes with high-recurring congestion and/or weekend/seasonal congestion. Priority should be given to interchanges with forecasted volume/capacity greater than 0.80.
Traffic Signal Controllers	**Urban/Suburban Arterials –** One per traffic signal connected to detectors at signal and mid-block. Priority should be given to arterial segments with forecasted volume/ capacity greater than 0.75, consistent with traffic signal warrants in the Caltrans Traffic Manual.
Signal Pre-emption/Priority Elements	**Urban/Suburban/Rural Arterials –** One per traffic signal controller at intersections with: • High emergency vehicle traffic • Near firehouses, police stations, hospitals • High bus transit vehicle traffic • Dense population/Central Business District (CBD) • Long cycle lengths
CMS	**Urban/suburban –** Upstream of major freeway-to-freeway interchanges and choke points.
	Rural – At severe weather regions or upstream of major decision points.
HAR	**Urban/suburban/rural –** When complex messages are needed to reach the travelers, such as at construction zones and severe weather regions.
Ramp Meters	**Urban/suburban –** Where forecasted volume is greater than 1,800 vehicles per hour at the rightmost freeway lane plus on-ramp, and at areas with significant merging problems (Forecasted volumes are generally obtained from regional travel demand models.). Priority should be given to already congested locations whenever possible in coordination with regional and local jurisdictions.

3.0 Traffic Simulation Methodology

This section describes the methodology used to identify the potential impacts and benefits resulting from the deployment of the TMS components, based on the guidelines presented in Section 2.0. Several methodologies were considered, but micro-simulation of the TMS strategies was ultimately selected as best suited to the needs of the study. Micro-simulation models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. The micro-simulation approach was selected for this study because it has the ability to accurately model the complex TMS strategies and its ability to animate the results for presentation purposes.

The project team developed micro-simulation networks of two representative corridors in California. Once the simulation models were developed and calibrated, deployment scenarios were simulated implementing the TMS strategies in various combinations and intensity. The results of the micro-simulation were then utilized in the benefit/cost analysis. Additional detail on the simulation methodology is presented below, while the micro-simulation results are discussed in Section 4.0. The methodology and results of the benefit/cost analysis are presented in Section 6.0.

Several micro-simulation tools were evaluated for this analysis. Based on this evaluation, the project team selected the Paramics™ micro-simulation software as the most appropriate tool to develop the TMS scenarios. As micro-simulation can be very resource-intensive, the project team looked at opportunities to utilize currently available simulation corridor models. The project team reviewed current Paramics™ micro-simulation efforts being conducted by the state and other regional agencies. These candidate corridors were evaluated against several criteria related to the complexity of using each corridor, the cost of incremental simulation work, and the degree to which the corridor was representative of a "typical" California freeway corridor. Using this set of criteria, the urban/suburban Interstate 680 (southbound only) corridor in the eastern San Francisco Bay Area, between Pleasanton and Milpitas, and the urban Interstate 405/Interstate 5 corridor in Orange County near Irvine were selected for the micro-simulation phase of this project. Figures 3.1 and 3.2 illustrate the overall view of both networks.

In addition to satisfying the criteria presented above, both networks were calibrated to existing traffic conditions. Since these networks were originally created for other specific studies, certain enhancements and modifications were necessary prior to the analysis of the TMS business processes.

The remainder of this section presents the methodology for the micro-simulation analysis for the I-680 and I-405/I-5 networks, performed by the Cambridge Systematics (CS) and University of California at Irvine (UCI) project teams. Table 3.1 presents an overview of the network development and enhancements for both networks, while Figure 3.3 lists all the TMS scenarios simulated in this study.

Figure 3.1 I-680 Study Corridor in the Bay Area

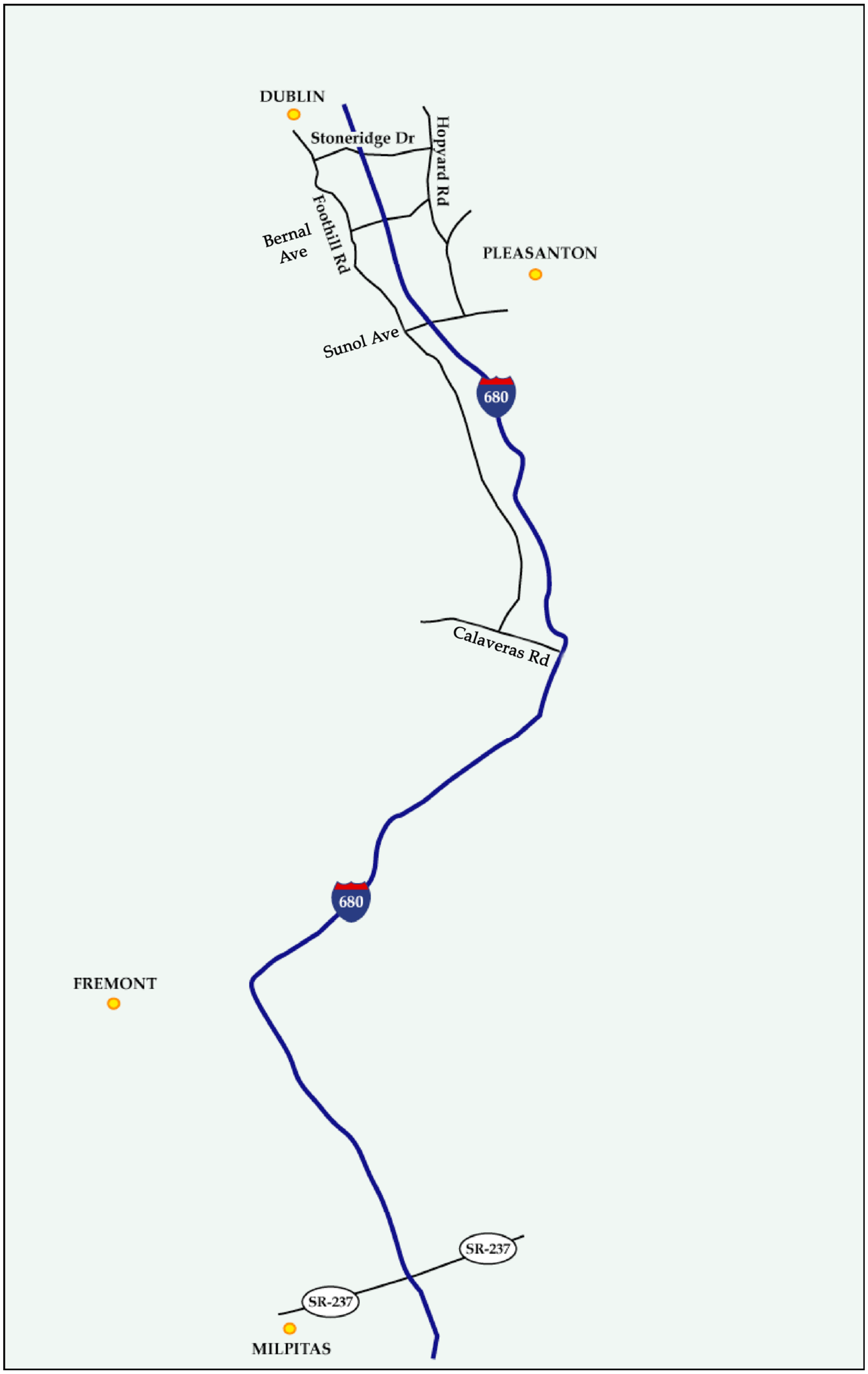


Figure 3.2 I-405/I-5 Study Corridor in Orange County

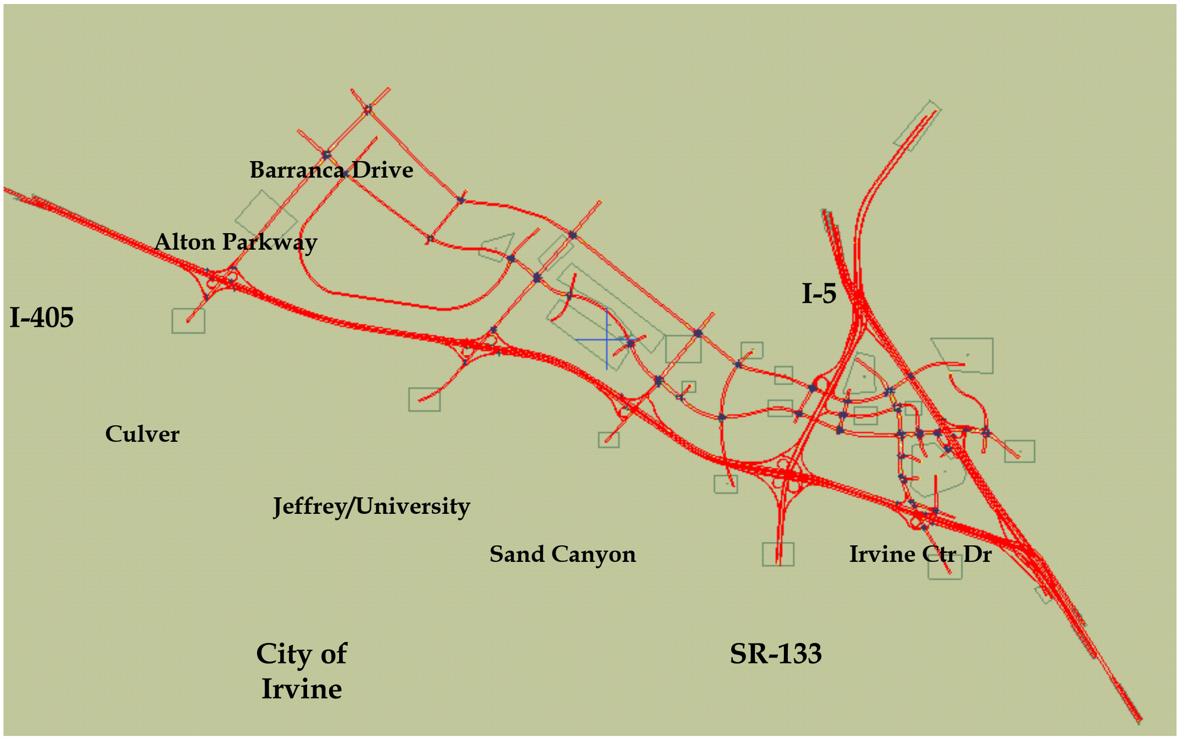
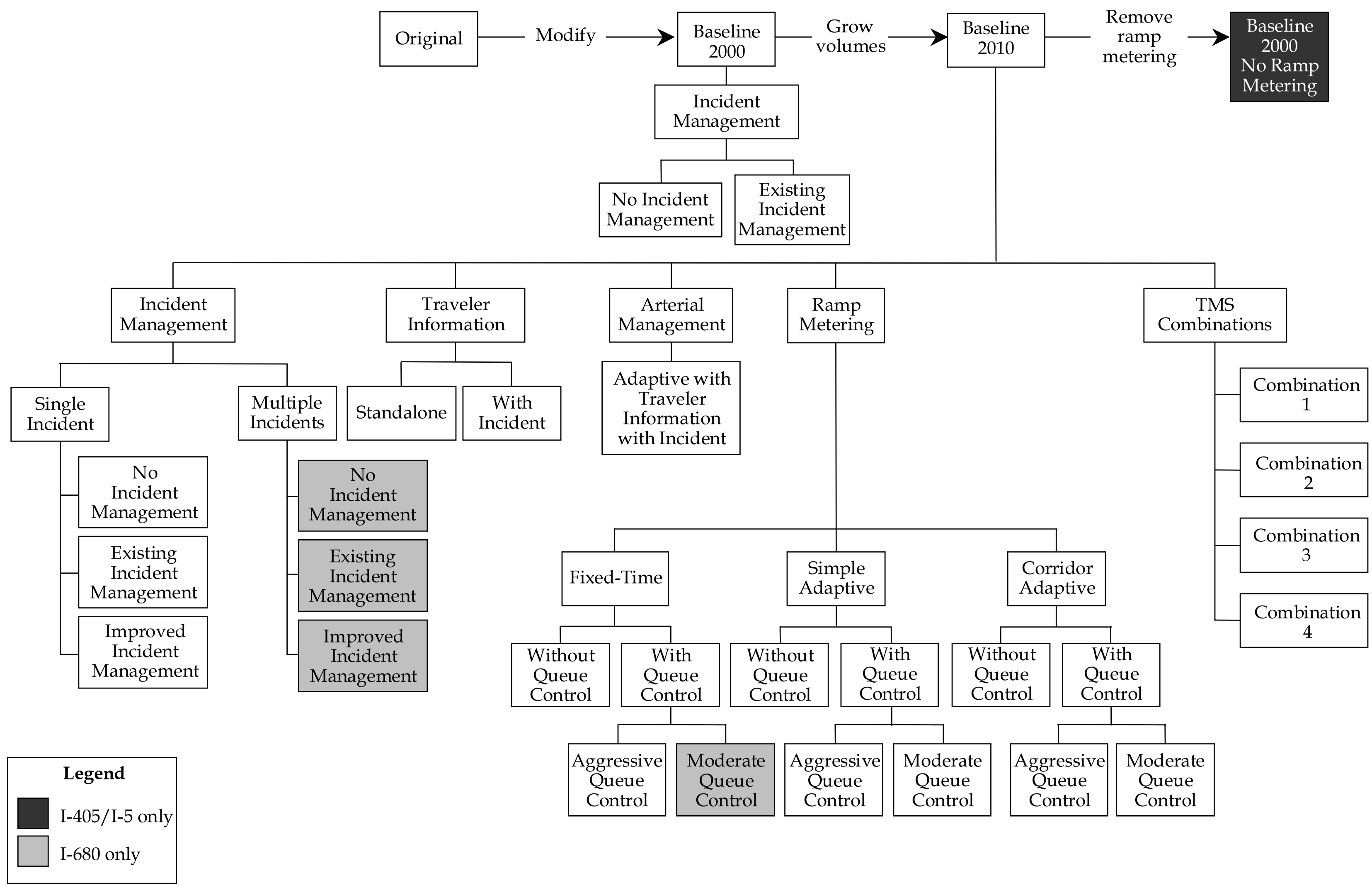


Table 3.1 Overview of Micro-Simulation Scenarios

Scenario	Analysis Year	Network Enhancements	Number of Scenarios I-680	Number of Scenarios I-405/I-5
Original	2000	• None	–	–
Baseline 2000	2000	• Add parallel arterials, signals and HOV lanes, as appropriate • Extend simulation run time and time-step • Use existing arterial management • Recalibrate network (using traffic volumes and travel times)	1	1
Year 2000 TMS Scenarios	2000	• Simulation of TMS business processes under existing traffic conditions	2	2
Baseline 2010	2010	• Year 2010 volumes from local Metropolitan Planning Organization (MPO) growth rates • Activate HOV lane (I-680 only)	1	1
Year 2010 TMS Scenarios	2010	• Simulation of TMS business processes under Year 2010 traffic conditions	22	18
		Total Scenarios Simulated	**26**	**22**

Figure 3.3 TMS Micro-Simulation Scenarios



■ 3.1 Baseline 2000 Network Development

In this task, the project team performed enhancement work to the original micro-simulation networks to better configure the networks to the needs of the analysis. Using the original networks, Baseline 2000 scenarios were developed for each network by adding or modifying certain network components, including:

- **Parallel arterials –** For the I-405/I-5 network, some geometric and/or volume adjustments were performed. For the I-680 network, Foothill Road and Hopyard Road were added to the original network, as shown in Figure 3.1. Traffic volumes on parallel arterials were obtained from local agencies, while the arterial trip distribution was based on the existing freeway distribution.

- **HOV lanes** were added as necessary to replicate existing/future network conditions, including all HOV lanes currently under construction. The I-680 network was enhanced by adding the HOV lane currently under construction between State Route (SR) 84 in Pleasanton and SR-237 in Milpitas. The modeled HOV lane was deactivated in the Baseline 2000 scenario, because the existing network does not include HOV lanes.

- The I-405/I-5 network currently operates **Fixed-Time Ramp Metering with Aggressive Queue Control** (details on this type of ramp metering system can be found in Section 3.5.4). The I-680, on the other hand, is not metered under existing conditions. The models were checked to confirm the proper representation of these strategies in the networks.

- Per Caltrans standard practice, the **micro-simulation "time-step"** was set at least four calculations per second for both networks. Time-step is a Paramics™ factor that controls the level of micro-simulation calculations; higher time-steps result in a "richer" set of results, but require longer computer run times.

- The **percentage of "familiar" drivers** was set at three percent for both networks, to account for route diversion and the existing market penetration of Traveler Information technologies. The Paramics™ default value for this factor is zero percent, which conservatively assumes that all commuters in the model are not familiar with the network and would stay at the major corridors and their pre-determined routes, no matter the congestion level.

- The **micro-simulation run times** were set to five hours between 5:00 a.m. and 10:00 a.m. (for the I-680 network), and four hours between 6:00 a.m. and 10:00 a.m. (for the I-405/I-5 network), in order to accommodate future traffic congestion, so the full benefits of TMS could be estimated.

- The **micro-simulation Origin-Destination (O-D) matrices and zone structures** were revised as needed to account for the parallel arterial modifications.

- Lastly, **major signalized intersections** were added to the I-680 network. The existing signal timings and offsets were obtained from local agencies and incorporated in the simulation model.

3.2 Baseline 2000 Model Calibration

This section presents the methodology and results of the Baseline 2000 calibration process for the I-680 and I-405/I-5 micro-simulation models, performed by the CS team and the UCI team, respectively. The micro-simulations were started 15 minutes to one-half hour prior to the study periods. This extra micro-simulation period was used as a "warm up" period to allow simulated vehicles to access the networks.

3.2.1 Calibration Acceptance Criteria

In the model calibration process, traffic volumes and travel times at selected links in the model networks were compared against existing field volumes and travel times. Appendix A lists the network links included in the traffic volume calibration process. The following criteria were used for acceptance of the calibrated micro-simulation networks:

- The modeled peak-period and peak-hour volumes at the selected links must be within 15 percent of the observed volumes for flows 700 to 2,700 vehicles per hour per lane (vphpl), or within 100 vph for flows less than 700 vph. These targets must be satisfied for 85 percent of the cases.

- Total modeled screenline flows (normally less than five links) must be within five percent of observed screenline flows for nearly all screenlines.

- The GEH statistic (a form of the chi-square statistic, which is designed to be tolerant of large errors in low flows) must be less than five for individual flows for 85 percent of the cases, and less than four for screenline totals for nearly all screenlines. The equation for the GEH statistic is presented below:

$$GEH = \sqrt{\frac{(M-C)^2}{(M+C)/2}}$$

  Where: M = modeled traffic flow; and
  C = Observed traffic flow.

- Simulated trip travel times must be within 15 percent of observed travel times for 85 percent of the routes. For I-680, trips include the freeway corridor end-to-end trips, and from the mid-point of the corridor to each of the two ends. For the I-405/I-5 corridor, travel time calibration was conducted using observed travel times between Culver Drive and Irvine Center Drive. Please refer to Appendix A for the freeway corridor routes considered for travel time calibration.

3.2.2 Calibration Results

For the I-680 network, all links selected for comparison met 100 percent of the peak-hour volumetric and GEH statistic criteria. During the peak period, 97 percent of the selected links satisfied the volumetric requirement, while 95 percent of the links met the GEH statistic requirement. Likewise, travel time comparisons were conducted for the Baseline 2000 simulation network, and the average travel time for all selected trips, both for the peak hour and the peak period, were within 15 percent of the average existing travel times within their respective time periods. The results of the I-680 network calibration are summarized in Table 3.2. Please refer to Appendix A for detailed results of the I-680 network calibration process.

Table 3.2 I-680 Baseline 2000 Network Calibration Results

	Compliance Rates		
Calibration Period	**Link Volume**	**GEH Statistic**	**Travel Time**
Peak hour	**100%**	**100%**	**100%**
Peak period	**97%**	**95%**	**100%**

Similarly, the I-405/I-5 network was calibrated based on traffic volume and travel time. According to the analysis, 87 percent of the links selected for calibration were within 15 percent of the existing peak-hour traffic volumes, while 96 percent met the GEH requirement. The peak-period calibration resulted in 96 percent compliance rate for the traffic volume comparison, and 98 percent compliance rate for the GEH criteria. The average simulated travel time resulted in 100 percent compliance rate when compared to the observed travel times. The results of the I-405/I-5 network calibration are summarized in Table 3.3. Detailed results of the I-405/I-5 calibration are presented in Appendix A.

Table 3.3 I-405/I-5 Baseline 2000 Network Calibration Results

	Compliance Rates		
Calibration Period	**Link Volume**	**GEH Statistic**	**Travel Time**
Peak hour	**87%**	**96%**	N/A
Peak period	**96%**	**98%**	**100%**

Based on the calibration methodology and acceptance criteria presented in Section 3.2.1, the Baseline 2000 simulation networks were calibrated and approved by Caltrans in May 2002.

3.3 Development of TMS Scenarios for Year 2000

Upon the calibration and approval of the Baseline 2000 networks, TMS scenarios were analyzed for Year 2000 traffic conditions. The simulation results were used to estimate benefits resulting from the deployment of existing TMS, such as incident management. Four TMS simulation scenarios (two scenarios per network) were modeled and run under Year 2000 conditions. These analysis scenarios are summarized in Table 3.4 and described in the following section.

Table 3.4 Year 2000 TMS Scenarios

TMS Business Process	Scenario	Approach
Incident Management	Baseline 2000 with Incident	Multiple incidents with no Incident Management; average incident duration at 33 minutes
	Existing	Multiple incidents with Existing IM; average incident duration at 26 minutes

3.3.1 Incident Management

Based on University of California at Berkeley (UC Berkeley) studies[1,2] on accidents and incidents in California corridors, there are approximately seven and four and one-half accidents/incidents occurring during a typical peak period on the study sections of I-680 and I-405/I-5, respectively. In this study, multiple incident scenarios were analyzed to gauge the impacts of incidents during a typical peak period. The approach adopted by the project team was to deploy multiple "average" incidents occurring at the top three incident locations, distributed evenly throughout the peak period. The most common incident locations were obtained from historical accident/incident data and/or FSP logs. "Average" incidents were assumed to be incidents that occur at the shoulder and do not

[1] "Freeway Service Patrol Evaluation," 1995, A. Skabardonis, H. Noeimi, K. Petty, D. Rydzewski, P. Varaiya, and H. Al-Deek.

[2] "Evaluation of the Freeway Service Patrol (FSP) in Los Angeles," 1998, A. Skabardonis, K. Petty, P. Varaiya, and R. Bertini.

block any lanes, causing passing vehicles to drive by at 10 mph during the first 10 minutes, and at 15 mph anytime thereafter.

Two incident scenarios were tested, including:

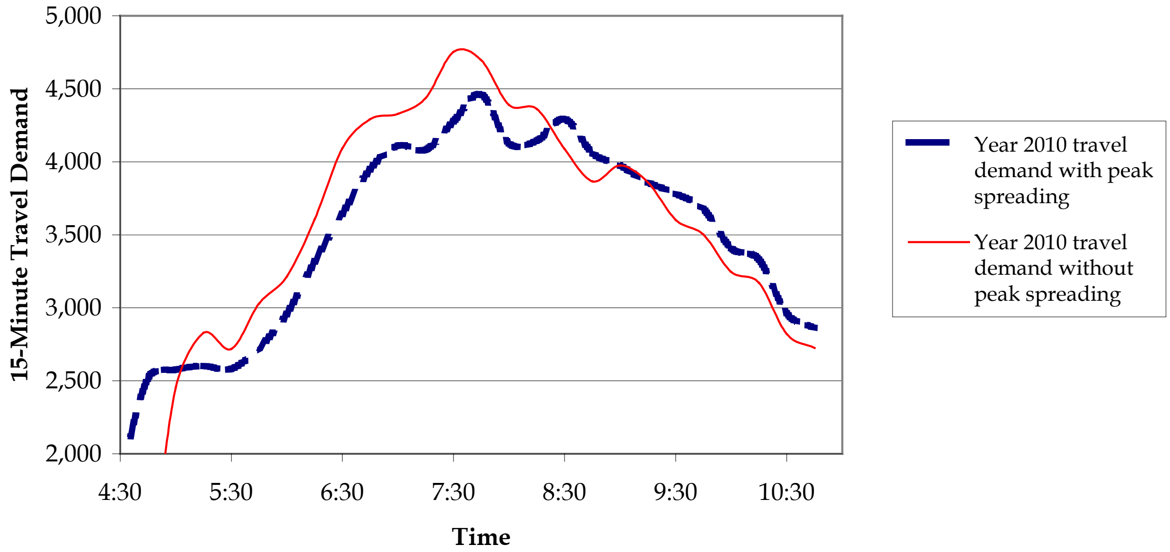
- The first simulation scenario tested the impacts of incidents without incident management. Each "average" incident was deployed and lasted for 33 minutes, which is the average incident duration when no Incident Management strategies are in place.
- The second simulation scenario explored the benefits of FSP-assisted incidents. This is the existing level of incident management deployment on both I-680 and I-405/I-5, where the incident duration for each incident averaged 26 minutes.

3.4 Baseline 2010 Network Development

Two Baseline 2010 scenarios (one for each network) were developed based on the calibrated Baseline 2000 micro-simulation networks. The existing Year 2000 traffic volumes were scaled up using the local Metropolitan Planning Organization's (MPO) traffic growth rates to reflect Year 2010 volumes. Metropolitan Transportation Commission (MTC) is the local MPO for the I-680 corridor, while the Orange County Transportation Authority (OCTA) is the MPO for the I-405/I-5 corridor. For the I-680 network, a travel growth rate of 25 percent was used, while a growth rate of 13 percent was used for the I-405/I-5 network. Additional assumptions include:

- Initial simulation test runs on the I-680 network with the 25 percent growth rate resulted in severe congestion, slow speeds, and vehicles not being released by the simulation onto the network. To mitigate this effect, "peak spreading" was applied as shown in Figure 3.4. Peak spreading assumes that some commuters (about 10 percent) would adjust their departure times (leaving earlier or later) to avoid the congested peak hour.
- The HOV lane on I-680 was activated in the Baseline 2010 scenario, to account for the future operations of the HOV lane.
- The Baseline 2010 scenario for the I-405/I-5 network includes fixed-time ramp metering with aggressive queue control. For details on this specific type of metering option, please refer to Section 3.5.4. An additional scenario for I-405/I-5 was also developed simulating a Baseline 2010 scenario without ramp metering.

Figure 3.4 I-680 Baseline 2010 Peak Spreading



3.5 Development of TMS Scenarios for Year 2010

In the Year 2010 analysis, each TMS business process was analyzed independently to estimate benefits associated with the deployment of individual TMS components. Simulation scenarios were then developed including combinations of TMS business processes to estimate impacts that may result from synergies between TMS business processes. In total, 22 future scenarios were scenarios analyzed for the I-680 network and 18 scenarios analyzed for the I-405/I-5 network, as summarized in Table 3.5 and depicted in Figure 3.3. The following sections present details of the proposed micro-simulation approach for each TMS business process.

3.5.1 Incident Management

Year 2010 simulation scenarios modeled single incident and multiple incident cases. The single incident scenarios consisted of an "average" incident at the most common incident location during the peak hour. The most common incident locations were obtained from historical incident data and/or FSP logs. An "average" incident was again assumed to be occurring on the roadway shoulder without blocking any lanes, causing passing vehicles to drive by at 10 mph during the first 10 minutes and at 15 mph anytime thereafter. Multiple incident scenarios were simulated only for the I-680 network. In this case, the "average" incidents were simulated at the top three incident locations, distributed evenly throughout the peak period.

Table 3.5 Year 2010 TMS Simulation Scenarios

TMS Business Process	Scenario	Approach
Incident Management	Baseline 2010 w/incident	• Single incident with no incident management (33 minutes incident duration) • Multiple incidents with no incident management (I-680 only)
	Existing	• Single incident with FSP only (26 minutes incident duration) • Multiple incidents with FSP only (I-680 only)
	Improved	• Single incident with FSP and CCTV (22 minutes incident duration) • Multiple incidents with FSP and CCTV (I-680 only)
Traveler Information	Standalone traveler information	• Increase percentage of familiar drivers (to account for CMS, HAR, Internet and media traveler information)
	Traveler information w/incident	• Increase percentage of familiar drivers (to account for CMS, HAR, Internet and media traveler information) • Incident with FSP only (26 minutes incident duration)
Arterial Management	Adaptive with traveler information	• Adaptive signal control (two sets of actuated signal timings, for normal and incident conditions) • Increase percentage of familiar drivers (to account for CMS, HAR, Internet and media traveler information)
Ramp Metering	Fixed-time	• Straight, fixed-time metering • HOV preferential lanes at all on-ramps • With and without queue control (x4 scenarios) • Aggressive and moderate queue control (I-680 only)
	Simple adaptive	• Simple adaptive metering • HOV preferential lanes at all on-ramps • With and without queue control (x4 scenarios) • Aggressive and moderate queue control (+2 scenarios)
	Corridor adaptive	• Corridor adaptive metering • HOV preferential lanes at all on-ramps • With and without queue control (x4 scenarios) • Aggressive and moderate queue control (+2 scenarios)
Combination 1	• Incident with FSP only (26 minutes incident duration) • Simple adaptive metering with aggressive queue control • CMS at major freeway-to-freeway interchanges • Adjust driver familiarity/perturbation factors	
Combination 2	• Same as Combination 1, but add adaptive arterial signal control	
Combination 3	• Same as Combination 1, but with corridor adaptive metering with aggressive queue control	
Combination 4	• Corridor adaptive metering without queue control • Adaptive arterial signal control	

Three sets of incident scenarios were tested, including:

1. The first set of simulation scenarios tested the impacts of incidents without incident management. The "average" incidents were deployed and lasted for 33 minutes, which is the average incident duration when no incident management strategies are in place.

2. The second set of simulation scenarios explored the benefits of FSP-assisted incidents. In this case, the incident duration was reduced to 26 minutes, which is the average duration of incidents when FSP is present.

3. The third set of simulation scenarios measured the benefits of FSP and improved detection (mainly through CCTVs) during incident conditions. The incident duration may be further reduced by approximately four minutes due to improved incident detection and verification, down to only 22 minutes for "average" incidents.

3.5.2 Traveler Information

Traveler Information includes CMS, HAR, and availability of pre-trip or en-route traveler information on the Internet or through general media. While in reality these components function differently and cater to different audiences, micro-simulation models estimate traveler information impacts using the percentage of "familiar" drivers in the network. Familiar drivers are defined as those who have perfect information about the traffic conditions, and know the best routes to reach their destinations. Based on studies of the expected traveler information market penetration in Year 2010, the percentage of familiar drivers was set at 15 percent, or 12 percent higher from its Year 2000 value of three percent.

A total of four scenarios (two scenarios per network) were simulated:

1. In the "standalone" scenario, the impact of traveler information technologies was analyzed under regular, non-incident conditions.

2. The second scenario assessed the impacts of traveler information during incident conditions. For this analysis, an "average" incident with duration of 26 minutes was deployed during the peak hour.

3.5.3 Arterial Management

Two scenarios (one for each network) were analyzed under this business process, primarily to gauge the impacts of advanced signal control algorithms, such as adaptive signal control. Adaptive signal control is capable of switching to different signal timing plans that adapt to changing travel demand and supply conditions.

The project team's approach to simulating adaptive signal controls include the development of two sets of signal timings, one for normal traffic conditions and another for incident conditions. Again, an "average" incident with duration of 26 minutes was used to help simulate the incident condition. The signals on the arterials used the existing set of timings until the incident occurred. Then, they switched to the incident signal timing set to accommodate detouring vehicles from the freeway mainline. After the incident, the timings returned to the existing signal timing set.

Existing signal timings were obtained directly from the Pleasanton (for the I-680 network) and Irvine (for the I-405/I-5 network) traffic departments. Since Paramics™ is limited in its signal optimization capabilities, the Synchro™ signal optimization tool was used to obtain the incident-optimized signal timings. Paramics™ was first used to identify how many vehicles diverted to the arterials during incident conditions. Then, based on these adjustments, Synchro™ was used to calculate the optimum signal timing under incident conditions. The optimized timings were then re-entered into Paramics™ to analyze the corresponding impacts.

- For the I-680 study area, Foothill Road and Hopyard Road are the simulated alternate routes paralleling the freeway corridor.

- In the I-405/I-5 study area, Alton Parkway and Barranca Parkway are the simulated alternate routes paralleling I-405, while Irvine Center Drive parallels I-5.

3.5.4 Ramp Metering

In total, 17 ramp metering scenarios (nine for the I-680 network, and eight for the I-405/I-5 network) were simulated. In all simulation scenarios, ramp metering is operational throughout the peak period. Three different types of ramp metering were analyzed:

1. The simplest type, **Fixed-Time Ramp Metering**, uses pre-set, historical parameters independent of changes to traffic on the freeway mainline or at the on-ramps.

2. **Simple Adaptive Ramp Metering** is sensitive to mainline traffic conditions, upstream of the on-ramp in question. The project team used the *Asservissement Linéaire d'Entrée Autoroutière* metering algorithm or "ALINEA"[3] to represent Simple Adaptive Metering.

3. The most advanced metering type analyzed in this study, the **Corridor Adaptive Ramp Metering**, takes into account both upstream and downstream traffic conditions before determining the appropriate metering rates. The "Bottleneck"[4] algorithm originally developed for use in the Seattle region was selected for use in this study.

Each scenario above was simulated *twice*, with and without queue control at the on-ramps. Queue control is a method to "flush out" all the vehicles queuing at the on-ramp by raising the metering rates to the maximum allowable level so that there is minimal impact on the

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[3] "ALINEA: A Local Feedback Control Law for On-Ramp Metering," 1991, M. Papageorgiou, H. Hadj-Salem, and J. Blosseville.

[4] "Evaluation of On-Ramp Control Algorithms," 2001, M. Zhang, T. Kim, X. Nie, W. Jin, L. Chu, and W. Recker.

local street network. Furthermore, two queue control levels were tested for each metering algorithm. Under the “aggressive” level, vehicles were metered at maximum metering rate of 1,200 vph. The “moderate” queue control level metered the vehicles at the on-ramp at a maximum rate of 800 to 1,100 vph, depending on the network and algorithm used. Table 3.6 lists the simulated queue control levels for all metering simulation scenarios.

Table 3.6 Micro-Simulated Ramp Metering Queue Control Levels

Algorithm	I-680 Network	I-405/I-5 Network
Fixed-time	Aggressive & moderate	Aggressive
Simple adaptive	Aggressive & moderate	Aggressive & moderate
Corridor adaptive	Aggressive & moderate	Aggressive & moderate

3.5.5 Combination of TMS Business Processes

Four scenarios combining several TMS business processes were developed. They include:

1. **“Combination 1” scenario –** Combination of simple adaptive ramp metering (with aggressive queue control), traveler information (15 percent familiar drivers), and incident management (single incident with a duration of 26 minutes);

2. **“Combination 2” scenario –** Combination of simple adaptive ramp metering (with aggressive queue control), traveler information (15 percent familiar drivers), incident management (single incident with a duration of 26 minutes), and adaptive arterial signal control;

3. **“Combination 3” scenario –** Combination of corridor adaptive ramp metering (with aggressive queue control), traveler information (15 percent familiar drivers), incident management (single incident with a duration of 26 minutes), and adaptive arterial signal control; and

4. **“Combination 4” scenario –** Combination of corridor adaptive ramp metering without queue control and adaptive arterial signal control.

4.0 Simulation Results

This section documents the approach for processing the Paramics™ micro-simulation output, and presents the summarized results. The micro-simulation analysis was used to identify changes in travel patterns and traffic conditions resulting from the deployment of the various TMS strategies in each of the scenarios. A sample screenshot of simulated I-680 corridor is shown in Figure 4.1. Performance measures for each TMS scenario were compared with the baseline scenario to quantify impacts. The performance measures considered in this study include speed, travel time, traffic volume, vehicle hours of travel (VHT), and vehicle miles of travel (VMT). Table 4.1 summarizes the performance measures obtained from the micro-simulation runs.

Figure 4.1 Screenshot of Micro-Simulated I-680 Network

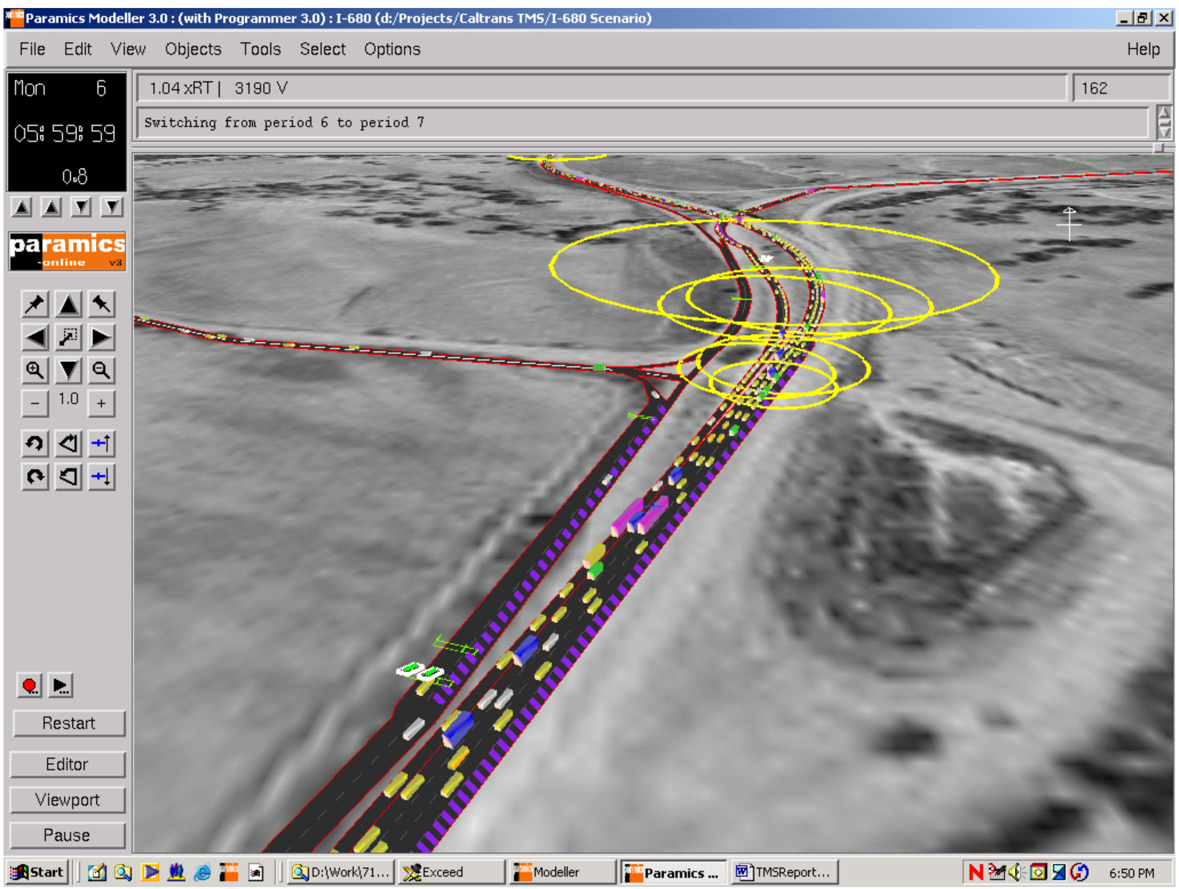


Table 4.1 Micro-Simulation Performance Measures

Measure	Unit
Travel time	Minutes
Speed	Mph
Volume	Vehicles
VHT	Vehicle-hours
VMT	Vehicle-miles

In order to disaggregate the results to a more usable scale, the simulated networks were divided into logical sections for reporting the performance measures. Dividing the networks into sections with similar characteristics provided a more robust set of corridor types for extrapolating the results to other California corridors (as discussed in Section 7.0).

In the case of the I-680 network, the study area was divided into three main sections (please refer to Figure 3.1 for the map of the I-680 study area):

- The **North Section**, located between the northern end of the network (north of Stoneridge Drive in Pleasanton) and Sunol Boulevard. This section has two parallel arterials, one to the west of I-680 (Foothill Road), and another to the east (Hopyard Road).
- The **Middle Section** has one parallel arterial (continuation of Foothill Road on the west side of I-680), located between Sunol Boulevard and Calaveras Avenue.
- The **South Section** between Calaveras Road and the southern end of the network (just south of SR-237 in Milpitas) has no parallel arterials modeled in the micro-simulation network.

Similarly, the I-405/I-5 network was divided into three sections. Since this study area involved two major corridors and numerous city streets, the network was categorized as I-405, I-5, and the rest of the network labeled "Others." Figure 3.2 illustrates the I-405/I-5 study area.

1. The **I-405 Section** contains the I-405 corridor and two modeled parallel arterials, Alton Parkway and Barranca Parkway, both located north of the freeway corridor;
2. The **I-5 Section** contains the I-5 corridor and its only modeled parallel arterial, Irvine Center Drive; and
3. SR-133 and all modeled city streets (except the parallel arterials noted above) are grouped together as the "**Others**."

For each corridor section, the resulting performance measures are further broken down by facility types, such as freeway, arterial, and on-ramp. Performance measures were generated for both the peak hour and peak period.

In generating the results, multiple runs of the simulation model were completed for each scenario to account for random variability in travel demand and supply conditions. Micro-simulation runs used a "seed number," a numeric user input used to generate a series of random parameters. Nine simulation runs were performed for each scenario to obtain statistically representative results. The *average* result from these runs was calculated and reported. Tables 4.2 and 4.3 present example micro-simulation outputs for one scenario from each network. The complete micro-simulation results for all TMS analysis scenarios for both networks are presented in Appendices B and C.

Once the micro-simulation results for all scenarios were processed, the project team then compared the results between scenarios, to measure the impacts of the TMS components simulated. Tables 4.4 and 4.5 present the summary comparison results for I-680 and I-405/I-5 TMS scenarios, respectively. There are three major groups of results shown in each table, including:

1. **Part I – No Incident.** Presents the impacts of TMS on recurrent congestion for all ramp metering scenarios and standalone traveler information;

2. **Part II – Incident Management with Multiple Incidents.** Presents the impacts of existing and improved incident management; and

3. **Part III – Single Incident.** Presents TMS impacts during single incident conditions, for incident management, traveler information, adaptive signal control and TMS combinations.

Each group of results in Tables 4.4 and 4.5 shows a progression of TMS deployments, from the simplest to the most complex. Comparisons are drawn against the category's *reference point* or baseline, which is highlighted in gray. For example, the reference point for the first group (Part I) in Table 4.4 is the Baseline 2010 scenario. The average network peak-hour speeds for the Baseline 2010 and simple adaptive ramp metering without queue control are 23.6 mph and 38.0 mph, respectively. Comparing the two shows that the TMS component resulted in a 61 percent improvement in speed for the peak hour. On the other hand, simple adaptive ramp metering with aggressive queue control resulted in an average network speed of 25.6 mph during the peak hour, or an eight percent improvement over the Baseline 2010 peak-hour speed. Besides average speed, other performance measure comparisons that are reported include VHT and VMT.

All results reported in Tables 4.4 and 4.5 represent entire network totals or averages (depending on the variable), including all facility types. For speed, a *positive change* indicates a *benefit* due to the TMS components deployed, while for the VHT comparisons, a *negative change* indicates a *benefit* or time savings caused by the deployment of TMS.

Table 4.2 Example Micro-Simulation Results – I-680 Baseline 2010

	North Section (with 2 parallel arterials)				Middle Section (with 1 parallel arterial)				South Section (without parallel arterials)			Total/Average			
	Fwy	On Ramp	Arterial	Tot/ Avg	Fwy	On Ramp	Arterial	Tot/ Avg	Fwy	On Ramp	Tot/ Avg	Fwy	On Ramp	Arterial	Tot/ Avg
Average Travel Time (min)															
Peak Hour	17.6	1.2	16.1	N / A	15.7	2.7	9.8	N / A	37.0	1.2	N / A	70.2	1.7	25.9	N / A
Peak Period	12.5	0.7	13.3	N / A	11.8	1.8	9.7	N / A	28.3	0.7	N / A	52.5	1.1	23.0	N / A
Average Speed (mph)															
Peak Hour	26.3	34.2	29.2	26.9	13.7	25.5	33.3	15.5	25.3	27.5	25.4	23.0	28.0	29.9	23.6
Peak Period	41.5	40.4	31.6	39.0	21.5	31.9	33.4	22.7	35.7	41.2	35.9	33.9	37.8	32.0	33.8
Average Volume (veh)															
Peak Hour	3,265	331	539	5,665	3,448	518	390	4,874	4,637	550	10,135	4,220	491	506	13,594
Peak Period	18,469	1,559	2,558	29,820	19,913	2,828	1,740	27,310	24,447	2,161	46,053	22,708	2,094	2,377	63,334
Total VHT (veh-hours)															
Peak Hour	951	27	289	1,267	898	47	64	1,008	2,859	107	2,965	4,707	180	353	52,41
Peak Period	3,833	71	1,130	5,033	3,900	174	282	4,356	11,526	251	11,778	19,259	496	1,412	21,167
Total VMT (veh-miles)															
Peak Hour	23,313	930	8,426	32,669	12,265	1,186	2,114	15,565	72,316	2,924	75,240	107,894	5,041	10,540	123,475
Peak Period	155,113	2,837	35,721	193,670	83,683	5,543	9,423	98,649	411,873	10,370	422,244	650,668	18,750	45,144	714,563

Table 4.3 Example Micro-Simulation Results – I-405/I-5 Baseline 2010

	I-405 Section (with 2 parallel arterials)				I-5 Section (with 1 parallel arterial)				Others (rest of network)				Network Total/Average			
	Fwy	On Ramp	Arterial	Tot/ Avg	Fwy	On Ramp	Arterial	Tot/ Avg	Fwy	On Ramp	Arterial	Tot/ Avg	Fwy	On Ramp	Arterial	Tot/ Avg
Average Travel Time (min)																
Peak Hour	7.9	3.7	19.9	N / A	3.2	1.1	3.0	N / A	2.4	0.5	8.5	N / A	5.2	2.1	10.1	N / A
Peak Period	7.2	3.3	19.8	N / A	3.0	1.1	2.8	N / A	2.3	0.5	8.4	N / A	4.9	1.9	9.8	N / A
Average Speed (mph)																
Peak Hour	54.7	36.5	33.0	50.4	55.0	45.0	25.7	52.0	57.7	42.3	22.9	49.1	55.0	38.5	30.9	50.8
Peak Period	58.2	38.2	33.9	53.7	57.7	45.5	27.3	54.7	58.7	42.3	23.4	49.7	58.2	40.2	31.9	53.7
Average Volume (veh)																
Peak Hour	19,377	658	1,693	21,728	18,273	463	2,194	20,930	5,174	367	469	6,011	42,825	1,488	4,356	48,669
Peak Period	70,085	2,182	5,442	77,709	64,135	1,617	7,633	73,386	16,706	1,236	1,542	19,484	150,926	5,035	14,618	170,579
Total VHT (veh-hours)																
Peak Hour	2,539	41	562	3,142	965	9	109	1,082	211	3	67	281	3,716	53	738	4,506
Peak Period	8,415	122	1,792	10,329	3,190	29	354	3,573	651	11	217	878	12,255	162	2,364	14,780
Total VMT (veh-miles)																
Peak Hour	137,494	1,459	18,524	157,476	52,888	382	2,819	56,089	12,193	133	1,537	13,864	202,575	1,975	22,879	227,429
Peak Period	487,613	4,571	60,698	552,882	183,728	1,364	9,681	194,773	38,234	449	5,096	43,779	709,575	6,384	75,475	791,434

Table 4.4 I-680 Average Simulation Results

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**	**Peak Hour**	**Percent Change**	**Change**	**Peak Period**	**Percent Change**	**Change**	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**
Part I. No Incident														
Baseline 2000	43.6	N / A	49.8	N / A	2,751	N / A	N / A	12,113	N / A	N / A	119,297	N / A	602,585	N / A
Baseline 2010	23.6	0	33.8	0	5,241	0	0	21,167	0	0	123,475	0	714,563	0
Fixed Ramp Metering without Queue Control	45.2	91	46.2	37	3,213	-39	-2,028	15,944	-25	-5,223	145,102	18	736,843	3
Fixed Ramp Metering with Moderate Queue Control	45.7	94	47.6	41	2,907	-45	-2,333	14,220	-33	-6,948	132,356	7	676,982	-5
Fixed Ramp Metering with Aggressive Queue Control	31.4	33	39.3	16	4,342	-17	-898	17,900	-15	-3,267	135,693	10	702,876	-2
Simple Adaptive Ramp Metering without Queue Control	38.0	61	44.6	32	3,477	-34	-1,763	15,570	-26	-5,597	136,386	10	693,608	-3
Simple Adaptive Ramp Metering with Moderate Queue Control	27.1	15	36.4	8	4,789	-9	-451	19,179	-9	-1,988	129,482	5	697,269	-2
Simple Adaptive Ramp Metering with Aggressive Queue Control	25.6	8	34.9	3	4,903	-6	-338	19,822	-6	-1,345	125,345	2	690,580	-3
Corridor Adaptive Ramp Metering without Queue Control	48.0	103	49.0	45	2,728	-48	-2,512	13,612	-36	-7,555	131,014	6	667,364	-7

Table 4.4 I-680 Average Simulation Results (continued)

Simulation Scenarios	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
	Peak Hour	Percent Change	Peak Period	Percent Change	Peak Hour	Percent Change	Change	Peak Period	Percent Change	Change	Peak Hour	Percent Change	Peak Period	Percent Change
Part I. No Incident (continued)														
Corridor Adaptive Ramp Metering without Queue Control + Adaptive Arterial Signal Control	48.2	104	49.1	45	2,705	-48	-2,536	13,531	-36	-7,636	130,319	6	664,535	-7
Corridor Adaptive Ramp Metering with Moderate Queue Control	28.9	22	38.1	13	4,507	-14	-734	18,258	-14	-2,909	129,869	5	694,401	-3
Corridor Adaptive Ramp Metering with Aggressive Queue Control	26.9	14	36.2	7	4,745	-9	-495	19,196	-9	-1,971	127,449	3	694,933	-3
Traveler Information	24.2	2	33.8	0.0	5,120	-2	-120	20,780	-2	-387	123,998	0.4	703,329	-2
Part II. Incident Management for Multiple Incidents														
Baseline 2000 with Incidents (33 min duration)	18.6	0	35.0	0	7,155	0	0	27,864	0	0	130,645	0	972,947	0
Year 2000 Existing Incident Management (26 min duration)	20.5	10	35.7	2	6,149	-14	-1,006	24,480	-12	-3,384	124,749	-5	875,136	-10
Baseline 2010 with Incidents (33 min duration)	18.2	0	31.3	0	7,307	0	0	28,726	0	0	132,174	0	898,644	0
Year 2010 Existing Incident Management (26 duration)	17.9	-2	31.5	1	7,371	1	65	27,691	-4	-1,035	131,347	-1	872,220	-3
Year 2010 Improved Incident Management (22 duration)	18.2	0.1	31.7	1	7,007	-4	-300	26,603	-7	-2,122	126,917	-4	841,060	-6

Table 4.4 I-680 Average Simulation Results (continued)

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**	**Peak Hour**	**Percent Change**	**Change**	**Peak Period**	**Percent Change**	**Change**	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**
Part III. Single Incident														
Baseline 2010	23.6	N / A	33.8	N / A	5,241	N / A	N / A	21,167	N / A	N / A	123,475	N / A	714,563	N / A
Baseline 2010 with Incident (33 min duration)	22.7	N / A	33.2	N / A	5,431	N / A	N / A	21,862	N / A	N / A	123,171	N / A	725,977	N / A
Existing Incident Management (26 min duration)	23.0	0	33.2	0	5,429	0	0	21,765	0	0	124,246	0	722,786	0
Add Traveler Information Only	24.0	4	33.6	1	5,194	-4	-234	20,975	-4	-790	124,124	-0.1	702,776	-3
Add Traveler Information + Adaptive Arterial Signal Control	23.2	1	33.7	2	5,284	-3	-145	21,298	-2	-466	121,923	-2	717,892	-1
Add Traveler Information + Simple Adaptive Ramp Metering with Aggressive Queue Control	25.1	9	33.8	2	5,021	-8	-408	19,596	-10	-2,169	126,130	2	662,532	-8
Add Traveler Information + Adaptive Arterial Signal Control + Simple Adaptive Ramp Metering with Aggressive Queue Control	25.2	10	33.4	1	5,093	-6	-336	18,552	-15	-3,213	128,268	3	620,393	-14

Table 4.4 I-680 Average Simulation Results (continued)

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	Peak Hour	Percent Change	Peak Period	Percent Change	Peak Hour	Percent Change	Change	Peak Period	Percent Change	Change	Peak Hour	Percent Change	Peak Period	Percent Change
Part III. Single Incident (continued)														
Add Traveler Information + Adaptive Arterial Signal Control + Corridor Adaptive Ramp Metering with Aggressive Queue Control	27.9	21	37.1	12	4,574	-16	-854	18,136	-17	-3,628	127,458	3	671,615	-7

Table 4.5 I-405/I-5 Average Simulation Results

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**	**Peak Hour**	**Percent Change**	**Change**	**Peak Period**	**Percent Change**	**Change**	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**
Part I. No Incident														
Baseline 2000	53.3	N / A	56.3	N / A	3,782	N / A	N / A	12,129	N / A	N / A	200,651	N / A	682,173	N / A
Baseline 2010 without Ramp Metering	51.1	0	54.1	0	4,492	0	0	14,959	0	0	228,942	0	809,359	0
Fixed Ramp Metering without Queue Control	50.7	-1	52.9	-2	4,531	1	38	15,445	3	487	228,978	0.0	815,960	1
Baseline 2010 with Fixed Ramp Metering with Aggressive Queue Control	50.8	-0.8	53.7	-0.8	4,506	0.3	13	14,780	-1	-179	227,429	-1	791,434	-2
Simple Adaptive Ramp Metering without Queue Control	50.9	-0.4	53.9	-0.5	4,461	-1	-31	14,708	-2	-251	226,265	-1	791,366	-2
Simple Adaptive Ramp Metering with Moderate Queue Control	50.4	-1	53.1	-2	4,598	2	106	15,395	3	437	230,544	0.7	815,887	1
Simple Adaptive Ramp Metering with Aggressive Queue Control	50.9	-0.4	53.9	-0.5	4,453	-1	-39	14,643	-2	-315	226,031	-1	787,523	-3
Corridor Adaptive Ramp Metering without Queue Control	Gridlocked													
Corridor Adaptive Ramp Metering without Queue Control + Adaptive Arterial Signal Control	Gridlocked													

Table 4.5 I-405/I-5 Average Simulation Results (continued)

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**	**Peak Hour**	**Percent Change**	**Change**	**Peak Period**	**Percent Change**	**Change**	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**
Part I. No Incident (continued)														
Corridor Adaptive Ramp Metering with Moderate Queue Control	50.1	-2	52.9	-2	4,620	3	128	15,426	3	468	230,313	1	813,681	1
Corridor Adaptive Ramp Metering with Aggressive Queue Control	50.9	-0.4	54.0	-0.3	4,434	-1	-59	14,482	-3	-477	224,966	-2	780,758	-4
Traveler Information	50.9	-1	54.2	0.1	4,462	-1	-30	14,266	-5	-692	225,914	-1	771,993	-5
Part II. Incident Management with Multiple Incidents														
Baseline 2000 with Incidents (33 min duration)	51.8	0	54.5	0	4,346	0	0	14,647	0	0	224,255	0	796,161	0
Year 2000 Existing Incident Management (26 min duration)	50.5	-2	53.6	-2	4,402	1	55	14,232	-3	-415	221,156	-1	759,157	-5
Baseline 2010 with Incidents (33 min duration)*	N / A	0	N / A	0	N / A	0	0	N / A	0	0	N / A	0	N / A	0
Year 2010 Existing Incident Management (26 min duration)*	N / A	-0.5%	N / A	1%	N / A	-1%	-49	N / A	-6%	-977	N / A	-2%	N / A	-5%
Year 2010 Improved Incident Management (22 min duration)*	N / A	0.1%	N / A	2%	N / A	-2%	-109	N / A	-7%	-1,085	N / A	-2%	N / A	-5%

Table 4.5 I-405/I-5 Average Simulation Results (continued)

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	Peak Hour	Percent Change	Peak Period	Percent Change	Peak Hour	Percent Change	Change	Peak Period	Percent Change	Change	Peak Hour	Percent Change	Peak Period	Percent Change
Part III. Single Incident														
Baseline 2010 with Fixed Ramp Metering with Aggressive Queue Control	50.8	N / A	53.7	N / A	4,506	N / A	N / A	14,780	N / A	N / A	227,429	N / A	791,434	N / A
Baseline with Incident (33 min duration)	50.8	N / A	53.1	N / A	4,517	N / A	N / A	15,456	N / A	N / A	228,433	N / A	817,228	N / A
Existing Incident Management (26 min duration)	50.7	0	53.2	0	4,506	0	0	15,239	0	0	227,490	0	807,289	0
Add Traveler Information Only	50.5	-0.5	53.5	0.6	4,526	0.4	19	14,756	-3	-482	227,246	-0.1	787,294	-2
Add Traveler Information + Adaptive Arterial Signal Control	50.7	-0.1	53.7	1	4,459	-1	-47	14,543	-5	-696	224,686	-1	778,794	-4
Add Traveler Information + Simple Adaptive Ramp Metering with Aggressive Queue Control	50.9	0.3	53.9	1	4,404	-2	-102	14,380	-6	-859	223,366	-2	773,398	-4
Add Traveler Information + Adaptive Arterial Signal Control + Simple Adaptive Ramp Metering with Aggressive Queue Control	51.3	1	54.1	2	4,330	-4	-176	14,248	-7	-991	221,197	-3	768,915	-5

Table 4.5 I-405/I-5 Average Simulation Results (continued)

	Average Speed (mph)				VHT (vehicle-hours)						VMT (vehicle-miles)			
Simulation Scenarios	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**	**Peak Hour**	**Percent Change**	**Change**	**Peak Period**	**Percent Change**	**Change**	**Peak Hour**	**Percent Change**	**Peak Period**	**Percent Change**
Part III. Single Incident (continued)														
Add Traveler Information + Adaptive Arterial Signal Control + Corridor Adaptive Ramp Metering with Aggressive Queue Control	50.9	0.4	53.8	1	4,520	0.3	14	14,327	-6	-911	229,319	1	769,096	-5

*Multiple incident impacts estimated from single incident micro-simulation runs.

In the simulations of some I-680 TMS scenarios, an average of two to three percent of the vehicles were not released into the network by the model program. This occurred because there was not enough capacity at the zone connectors to add more vehicles into the network. In order to achieve analytical consistency, the VHT and VMT performance measures were normalized using the proportions of vehicle volumes released in each TMS scenarios over vehicle volumes released in the Baseline 2010 scenario.

The goal of the micro-simulation was to estimate the impacts resulting from the deployment of TMS investments. The main performance measure used in the estimation of impacts is vehicle-hours of travel (VHT). The following sections discuss the resulting VHT impacts for each simulated TMS scenario.

4.1 Simulation Results – Ramp Metering and Traveler Information Under No-Incident Conditions

This section presents the VHT impacts resulting from the deployment of TMS scenarios under regular recurring peak-period congestion (without any incidents), including ramp metering scenarios and standalone traveler information. The peak-period impacts of TMS technologies on VHT are summarized in Table 4.6.

Table 4.6 Peak-Period VHT Impacts – Ramp Metering and Traveler Information Under No Incident Conditions

Simulation Scenario	I-680	I-405/I-5
Baseline 2010 (Baseline for I-680)	0%	0%
Fixed ramp metering with aggressive queue control (QC) (Baseline for I-405/I-5)	-15%	-1%
Fixed ramp metering with moderate QC	-33%	N/A
Fixed ramp metering without QC	-25%	3%
Simple adaptive ramp metering with aggressive QC	-6%	-2%
Simple adaptive ramp metering with moderate QC	-9%	3%
Simple adaptive ramp metering without QC	-26%	-2%
Corridor adaptive ramp metering with aggressive QC	-9%	-3%
Corridor adaptive ramp metering with moderate QC	-14%	3%
Corridor adaptive ramp metering without QC	-36%	Gridlock
Corridor adaptive ramp metering without QC + Adaptive arterial signal control	-36%	Gridlock
Standalone traveler information	-2%	-5%

Several conclusions can be drawn from the results shown in Table 4.6:

- Overall, ramp metering is a good investment of public funds in California. The vast majority of ramp metering simulation scenarios generated travel time savings (designated by the minus signs in Table 4.6).
- Ramp metering is more effective under congested conditions. Travel time benefits are greater in the I-680 corridor, which is more congested than the I-405/I-5 corridor.
- More sophisticated ramp metering deployments generally produce better travel time savings than less sophisticated deployments. In this regard, corridor adaptive ramp metering provides greater benefits than simple adaptive ramp metering, which provides greater benefits than fixed-time ramp metering.
- Unconstrained ramp metering (without queue control) generally produces greater travel time savings than constrained ramp metering (with queue control). It is possible, however, that queue control is optimized so that moderate QC produces more travel time benefits than aggressive QC. A summary of the queue control impacts is shown in Table 4.7.

Table 4.7 Impacts of Queue Control (QC) on Peak-Period VHT

Type of Ramp Metering Deployment	No QC	Moderate QC	Aggressive QC
I-680 Network			
Fixed-time	-25%	-33%	-15%
Simple adaptive	-26%	-9%	-6%
Corridor adaptive	-36%	-14%	-9%
I-405/I-5 Network			
Fixed-time	3%	N/A	-1%
Simple adaptive	-2%	3%	-2%
Corridor adaptive	Gridlock	3%	-3%

- Adaptive arterial signal control offers some relief to the negative impacts of unconstrained ramp metering at the local streets. In the I-680 simulations for example, adaptive arterial signal control generated an additional 80 vehicle-hours of savings in the peak period. Conversely, in the I-405/I-5 simulations, the implementation of unconstrained corridor adaptive ramp metering caused gridlock on the local street network; queues extended beyond the freeway on-ramps onto the local streets causing gridlock. Even though it is unlikely that gridlock would have occurred in real life (drivers would divert to alternative routes not included in the simulation), this example highlights the caveat that ramp metering operations have great potential, but must be carefully planned to minimize negative impacts.

- Traveler information generates travel time savings between two and five percent during recurring congestion conditions.

4.2 Simulation Results – Incident Management

This section presents the VHT impacts resulting from the deployment of incident management including existing and advanced incident management under Year 2000 and Year 2010 traffic conditions. Several conclusions can be drawn from the results shown in Table 4.8:

- Overall, incident management generated travel time savings (designated by the minus signs in Table 4.8).
- More sophisticated incident management operations generally produce better travel time savings than less sophisticated deployments. In this regard, advanced incident management provides greater benefits than existing incident management.

Table 4.8 Peak-Period VHT Impacts – Incident Management

Simulation Scenario	I-680	I-405/I-5
Year 2000		
Baseline 2000 with incidents (33 min)	0%	0%
Existing incident management (26 min)	-12%	-3%
Year 2010		
Baseline 2010 with incidents (33 min)	0%	0%
Existing incident management (26 min)	-4%	-6%
Improved incident management (22 min)	-7%	-7%

4.3 Simulation Results – Combinations of TMS Under Incident Conditions

This section presents the VHT impacts resulting from the deployment of combinations of TMS scenarios under incident conditions, including traveler information, arterial management, and ramp metering. The results are summarized in Table 4.9. In summary:

- Traveler information produces travel time benefits between three and four percent;
- With adaptive arterial signal control added to traveler information, the simulations showed a travel time benefit of up to five percent;
- The combination of traveler information and simple adaptive ramp metering with aggressive queue control produced travel time savings between six and 10 percent;
- The mix of traveler information, simple adaptive ramp metering with aggressive queue control, and adaptive arterial signal control showed a travel time benefit of seven to 15 percent; and
- Finally, by combining traveler information, adaptive arterial signal control, and corridor adaptive ramp metering with aggressive queue control, the simulations produced travel time benefits that ranged from six to 17 percent.

Table 4.9 Peak-Period VHT Impacts – Combinations of TMS Under Incident Conditions

Year 2010 Simulation Scenario	I-680	I-405/I-5
Existing incident management (26 min)	0%	0%
Add traveler information	-4%	-3%
Add traveler information + Adaptive arterial signal control	-2%	-5%
Add traveler information + Simple adaptive ramp metering with aggressive queue control (QC)	-10%	-6%
Add traveler information + Adaptive arterial signal control + Simple adaptive ramp metering with aggressive QC	-15%	-7%
Add traveler information + Adaptive arterial signal control + Corridor adaptive ramp metering with aggressive QC	-17%	-6%

Several conclusions can be drawn from the results shown in Table 4.9:

- TMS are more effective under congested conditions. Travel time benefits are greater in the I-680 corridor, which is more congested than the I-405/I-5 corridor.
- Generally, more complex TMS combinations produce greater travel time savings.

5.0 Secondary Research

As part of the Financial Plan effort, secondary research was conducted to provide comparable empirical data from relevant research regarding the benefits and costs of TMS. These data were used to validate the simulation findings. The CS team identified and searched ITS and transportation agency web sites to find TMS information that is current and relevant. Trade press and databases searched include Traffic Technology International; Roads and Bridges; The Journals of the Association of Metropolitan Planning Organizations; the Institute of Transportation Engineers (ITE) and American Public Works Association; U.S. DOT's electronic data library; U.S. DOT's ITS costs and benefits database; as well as state and other transportation agency DOT web sites.

This section summarizes the findings from the secondary research, or the "buttressing" effort. The performance measures reported vary for each TMS business process, but the two most common performance measures include travel speed and traffic volume. The following sections report secondary research results for travel speeds on freeways and arterials. The complete results of the secondary research effort can be found in Appendix D.

■ 5.1 Ramp Metering and Traveler Information Under No-Incident Conditions

The findings from the secondary research closely validate the results of the I-680 micro-simulations, especially the "without Queue Control" ramp metering scenarios. The impacts of TMS on I-405/I-5 were generally at the low end of the comparison range. The peak-period speed comparisons between the two micro-simulated networks and the secondary research are summarized in Table 5.1.

■ 5.2 Incident Management

Limited field data were available regarding incident management impacts. Table 5.2 summarizes the speed comparison between the two simulated networks and the results of the secondary research.

Table 5.1 Buttressing for Peak-Period Speed Impacts – Ramp Metering and Traveler Information Under No-Incident Conditions

Simulation Scenario	I-680	I-405/I-5	Secondary Research Range
Baseline 2010 (Baseline for I-680)	0%	0%	0%
Fixed ramp metering with aggressive queue control (QC) (Baseline for I-405/I-5)	F: 20% A: 0.4%	F: -0.2% A: -1%	F: 29%
Fixed ramp metering with moderate QC	F: 53% A: -14%	N/A	F: 29%
Fixed ramp metering without QC	F: 70% A: -19%	F: -0.3% A: -1%	F: 5-81%
Simple adaptive ramp metering with aggressive QC	F: 5% A: 0.1%	F: 0.0% A: -0.1%	F: 39%
Simple adaptive ramp metering with moderate QC	F: 10% A: -2%	F: -1% A: -1%	F: 39%
Simple adaptive ramp metering without QC	F: 40% A: -9%	F: 0.0% A: 0.0%	F: 6-57%
Corridor adaptive ramp metering with aggressive QC	F: 10% A: -1%	F: 1% A: -0.4%	F: 9-60%
Corridor adaptive ramp metering with moderate QC	F: 15% A: -0.2%	F: -1% A: -1%	F: 9-60%
Corridor Adaptive ramp metering without QC	F: 53% A: 0.4%	Gridlock	F: 20-58%
Corridor adaptive ramp metering without QC + Adaptive arterial signal control	F: 54% A: 0.0%	Gridlock	N/A
Standalone traveler Information	F: 1% A: -1%	F: 1% A: -1%	N/A

F – freeway, A – arterial.

Table 5.2 Buttressing for Peak-Period Speed Impacts – Incident Management

Simulation Scenario	I-680	I-405/I-5	Secondary Research Range
Year 2000			
Baseline 2000 with incidents (33 min)	0%	0%	0%
Existing incident management (26 min)	F: 2% A: 2%	F: -2% A: 0.2%	N/A
Year 2010			
Baseline 2010 with incidents (33 min)	0%	0%	0%
Existing incident management (26 min)	F: 1% A: 0.3%	F: 2% A: -3%	N/A
Improved incident management (22 min)	F: 1% A: 1%	F: 3% A: -4%	F: 7-19%

F: freeway, A: arterial.

5.3 Combinations of TMS Under Incident Conditions

TMS improved average travel speeds during incident conditions, ranging from one to 14 percent on the freeway and up to two percent on the arterials. When traveler information and ramp metering were deployed, freeway speeds improved, but arterial speeds usually declined. Table 5.3 summarizes the speed impact comparisons. The secondary research shows higher than simulated speed impacts, especially on the freeway – it is likely that this is due to differences in the methodologies and extent of freeway speed measurements.

Table 5.3 Buttressing for Peak-Period Speed Impacts – Combinations of TMS Under Incident Conditions

Year 2010 Simulation Scenario	I-680	I-405/I-5	Secondary Research Range
Existing incident management (26 min)	0%	0%	0%
Add standalone traveler information	F: 2% A: -1%	F: 2% A: -1%	F: 11-15%
Add standalone traveler information + Adaptive arterial signal control	F: 1% A: 0.1%	F: 2% A: 1%	N/A
Add standalone traveler information + Simple adaptive ramp metering with aggressive queue control (QC)	F: 4% A: -2%	F: 4% A: 0.4%	N/A
Add standalone traveler information + Adaptive arterial signal control + Simple adaptive ramp metering with aggressive QC	F: 3% A: -2%	F: 4% A: 2%	F: 16-62% A: 3-19%
Add standalone traveler information + Adaptive arterial signal control + Corridor adaptive ramp metering with aggressive QC	F: 14% A: 1%	N/A	F: 16-62% A: 3-19%

F: freeway, A: arterial.

6.0 Benefit Analysis

This section describes the benefit analysis of TMS field elements based upon the micro-simulation results presented in Section 4.0. Separate analyses were conducted for the I-680 and the I-405/I-5 simulation networks. The benefit evaluation followed the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) methodology. Cal-B/C is the official Caltrans benefit-cost model for evaluating transportation capital investments. As in the Cal-B/C methodology, the benefits related to the deployment of TMS field elements were compared over a 20-year life cycle. The analysis compared traffic conditions in baseline simulation scenarios (the "without" scenario) to TMS simulations (the "with" scenarios).

As depicted in Figure 6.1, most of the benefits were estimated based on travel speed and traffic volume improvements obtained from the micro-simulations. Quantifying safety benefits relied upon knowledge of how TMS investments affect accident rates; safety impacts of TMS came from secondary research presented in Section 5.0 and in Appendix D. Secondary research indicated that TMS investments could generate potential accident rate reductions of more than 15 percent. These potential accident rate reductions were included in the benefit-cost analysis, consistent with the Cal-B/C methodology. However, safety benefits were not included in the extrapolation of TMS benefits statewide (see Section 7.0) to provide a conservative estimate of overall benefits.

The remainder of this section describes in detail the benefit analysis methodology, the economic assumptions and values used in the analysis, and the results for the I-680 and the I-405/I-5 simulation networks.

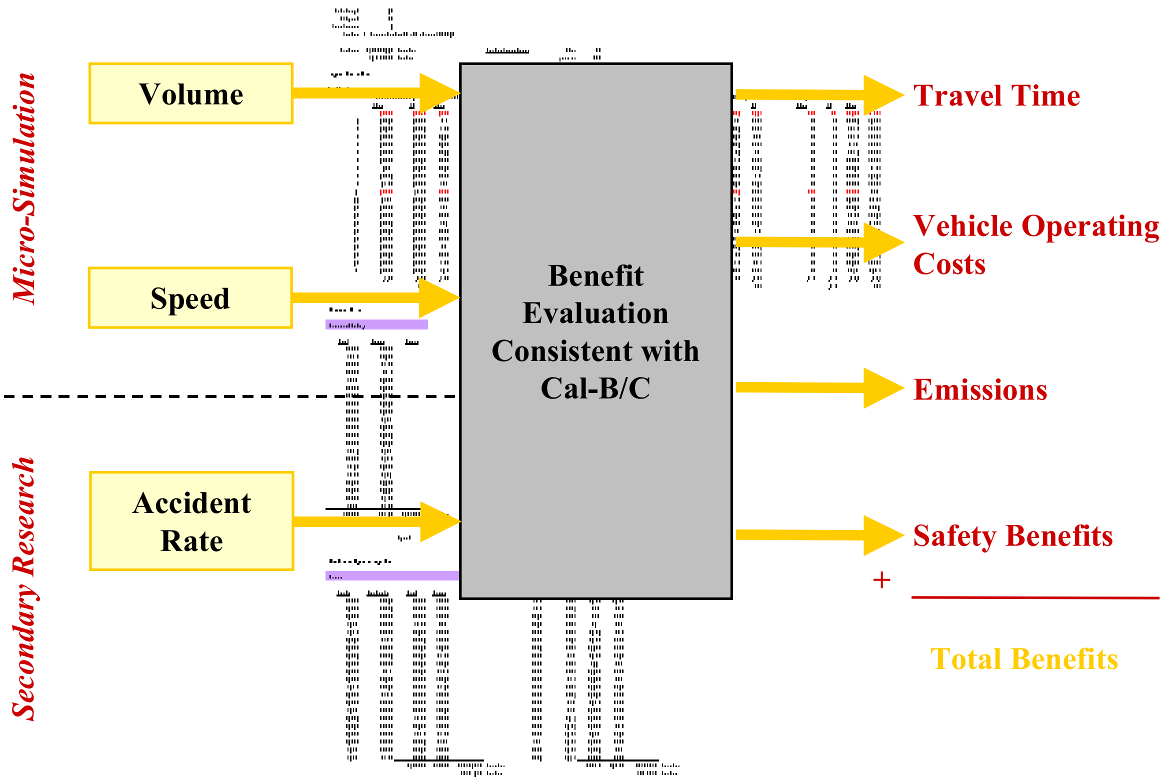
6.1 Benefit Analysis Methodology

The benefit analysis was conducted in a manner consistent with Cal-B/C. Caltrans uses Cal-B/C to evaluate the cost effectiveness of projects proposed for the Interregional Transportation Improvement Program (ITIP). The Cal-B/C model was developed to provide a common framework for evaluating several highway and rail infrastructure projects over a short period of time.

Cal-B/C estimates the dollar value of benefits associated with four types of user impacts, including the following:

1. Travel time savings;
2. Vehicle operating cost savings;
3. Emission reductions; and
4. Safety benefits.

Figure 6.1 TMS Benefit Analysis Process



Except in the case of emissions, Cal-B/C does not measure benefits that accrue to non-travelers, such as agency cost savings and reduced maintenance costs. The methodology also ignores other public benefits, such as shortened peak periods and improved travel time reliability. In this sense, a Cal-B/C type of benefit analysis is a conservative estimate of public benefits resulting from TMS investments.

The evaluation considered benefits and disbenefits (negative benefits) occurring on three separate parts of the simulation networks, including freeways, ramps, and arterials. These facility types were analyzed separately, because the benefits in one portion of the network could lead to disbenefits on another. For instance, ramp metering strategies typically result in higher speeds and reduced travel times on freeways, but these benefits could come at the cost of longer wait times at on-ramps. The benefit analysis considered both the benefit of reduced travel times on freeways and the disbenefit of longer ramp waits. In the case of ramp metering, the freeway benefits outweighed the ramp disbenefits.

Since there are four types of user benefits and three separate pieces of the simulation networks to consider, the benefit evaluation of each TMS investment required the estimation of 12 benefit streams (one for each user benefit on each portion of the network) over a 20-year period. In Section 7.0, these benefits are compared to life-cycle costs, which include the up-front capital investment and ongoing operating, maintenance, and replacement costs.

6.1.1 Benefit Estimation

Benefits were estimated for each of the TMS scenarios described in Section 4.0 for the I-405/I-5 and I-680 networks. These scenarios represented stand-alone TMS strategies (e.g., ramp metering or incident management), as well as combinations of TMS strategies. The I-680 corridor currently has very little TMS investment. The baseline simulations were used as the "without" case for the analysis. Since the I-405/I-5 network already has simple adaptive ramp metering with queue control, the case of no ramp metering was used as the "without" case.

As described in Section 7.0, the micro-simulation results were used in conjunction with other supporting benefit data from California and the rest of the country to derive statewide benefits. In general, the I-680 results were used to derive benefits for severely congested corridors, while the I-405 results were used to derive benefits for less severely congested corridors.

Travel speeds and traffic volumes on highways were an important component of the benefit analysis. Highway speed and volume information came from the Intermodal Transportation Management System (ITMS), which is a decision-support system developed by Caltrans for multimodal planning. The system contains current and future projections of highway speeds and volumes by corridor that come directly from travel forecasts used for regional planning models maintained by California Metropolitan Planning Organizations (MPOs).

6.1.2 Economic Assumptions and Values

Cal-B/C provided all the values and rate tables necessary for the benefit-cost analysis of TMS investments. Economic values include the following:

- **Real discount rate –** Cal-B/C uses a real discount rate of six percent, which is based on the historical real interest rate and long-term average real rate of return on public fund investments, plus a risk premium to discount all future costs and benefits to the present.
- **Value of time –** The Cal-B/C model uses a value of $8.16 per hour (in year 2000 dollars) for automobile travelers.
- **Vehicle operating costs –** Cal-B/C provides a lookup table for the fuel consumption (in gallons per mile) of vehicles as a function of speed.
- **Accident costs –** The model provides average costs for roadway fatality, injury, and property damage only (PDO) accidents.
- **Emissions costs –** The model provides health cost estimates per ton of emissions for CO, NO_X, PM_{10}, and VOC. Emission rates are derived from the EMFAC7 model maintained by the California Air Resources Board.

More details about the assumptions contained in Cal-B/C are available in the technical supplement to the Cal-B/C user's guide.[5]

6.2 Benefit Results for Simulated Networks

Benefits were quantified for each of the TMS deployment scenarios simulated for the I-680 and the I-405/I-5 networks. Tables 6.1 and 6.2 show the results of the benefits estimation. Benefits are presented as cumulative benefits for a 20-year life-cycle; for example, the benefits of corridor adaptive ramp metering without queue control are the total benefits relative to no ramp metering at all. The incremental benefits of moving from simple adaptive ramp metering without queue control to corridor adaptive ramp metering without queue control would be calculated as the difference in benefits for the two analysis scenarios.

The benefits presented in Tables 6.1 and 6.2 were used to identify the most promising TMS deployments that could be implemented in the short and medium term. The benefits for these TMS scenarios were extrapolated statewide for the TMS investment prioritization as described in Section 7.0. Tables 6.3 and 6.4 show incremental benefits for selected TMS simulation scenarios. Tables 6.3 and 6.4 show the incremental benefits of moving from one TMS deployment scenario to another in anticipation of the prioritization presented in Section 7.0.

[5] California Department of Transportation, *California Life-Cycle Benefit/Cost Analysis Model: Technical Supplement to the User's Guide*, written by Booz·Allen & Hamilton, Inc., on behalf of the California Department of Transportation, September 1999.

Table 6.1 20-Year Cumulative TMS Benefits for the I-680 Simulation Network (in $ million)

Scenarios	Travel Time	Vehicle Op. Costs	Emissions	Safety	Total*
Part I. No Incident					
Fixed ramp metering without queue control	$226	-$42	-$35	$6	**$156**
Fixed ramp metering with moderate queue control	$324	$45	-$27	$48	**$390**
Fixed ramp metering with aggressive queue control	$156	$22	-$9	$47	**$215**
Simple adaptive ramp metering without queue control	$291	$63	-$19	$49	**$384**
Simple adaptive ramp metering with moderate queue control	$95	$23	-$4	$47	**$161**
Simple adaptive ramp metering with aggressive queue control	$64	$28	-$2	$49	**$140**
Corridor adaptive ramp metering without queue control	$352	$63	-$26	$52	**$441**
Corridor adaptive ramp metering without queue control + adaptive arterial signal control	$356	$66	-$26	$53	**$449**
Corridor adaptive ramp metering with moderate queue control	$139	$31	-$7	$48	**$211**
Corridor adaptive ramp metering with aggressive queue control	$94	$27	-$4	$49	**$166**
Traveler information	$18	$14	$1	$0	**$34**
Part II. Incident Management with Multiple Incidents					
Existing incident management (26-min duration)	$50	$35	$2	$62	**$149**
Improved incident management (22-min duration)	$103	$73	$3	$100	**$280**
Part III. Single Incident					
Existing incident management (26-min duration)	$5	$5	$0	$29	**$39**
Improved incident management (22-min duration)	-$3	$1	$0	$43	**$41**
Add traveler information only	$42	$32	$1	$31	**$106**
Add traveler information + adaptive arterial signal control	$27	$15	$0	$31	**$73**
Add traveler information + simple adaptive ramp metering with aggressive queue control	$103	$73	$1	$53	**$230**
Add traveler information + adaptive arterial signal control + simple adaptive ramp metering with aggressive queue control	$153	$123	$4	$60	**$340**
Add traveler information + adaptive arterial signal control + corridor adaptive ramp metering with aggressive queue control	$173	$72	-$3	$55	**$296**

*May not equal the sum of benefit columns due to rounding.

Table 6.2 20-year Cumulative TMS Benefits for the I-405/I-5 Simulation Network (in $ million)

Scenarios	Travel Time	Vehicle Op. Costs	Emissions	Safety	Total*
Part I. No Incident					
Fixed ramp metering without queue control	$(23)	$(4)	$0	$31	**$4**
Baseline 2010 with fixed ramp metering with aggressive queue control	$8	$24	$8	$40	**$81**
Simple adaptive ramp metering without queue control	$12	$24	$7	$40	**$83**
Simple adaptive ramp metering with moderate queue control	$(21)	$(3)	$4	$35	**$15**
Simple adaptive ramp metering with aggressive queue control	$15	$28	$8	$40	**$92**
Corridor adaptive ramp metering without queue control	Grid-locked				
Corridor adaptive ramp metering without queue control + adaptive arterial signal control	Grid-locked				
Corridor adaptive ramp metering with moderate queue control	$(22)	$(0)	$2	$34	**$14**
Corridor adaptive ramp metering with aggressive queue control	$23	$37	$9	$42	**$110**
Traveler information	$25	$20	$(0)	$3	**$47**
Part II. Incident Management for Multiple Incidents**					
Existing incident management (26-min duration)	$19	$42	$18	$26	**$105**
Improved incident management (22-min duration)	$23	$45	$18	$38	**$125**
Part III. Single Incident					
Existing incident management (26-min duration)	$10	$11	$2	$25	**$48**
Add traveler information only	$34	$32	$0	$26	**$93**
Add traveler information + adaptive arterial signal control	$44	$43	$3	$29	**$120**
Add traveler information + simple adaptive ramp metering with aggressive queue control	$41	$72	$3	$71	**$187**
Add traveler information + adaptive arterial signal control + simple adaptive ramp metering with aggressive queue control	$48	$78	$5	$73	**$204**
Add traveler information + adaptive arterial signal control + corridor adaptive ramp metering with aggressive queue control	$44	$83	$5	$72	**$205**

*May not equal the sum of benefit columns due to rounding.

**Multiple incident impacts estimated from single incident micro-simulation runs.

Table 6.3 Incremental TMS Benefits for the I-680 Simulation Network (in $ million)

TMS Strategy	Travel Time	Vehicle Op. Costs	Emissions	Safety	Total*
Ramp metering					
Simple adaptive with queue control	$64	$28	-$2	$49	**$140**
Make queue control more moderate	$31	-$5	-$2	-$2	**$21**
Change to bottleneck with queue control	$44	$8	-$2	$1	**$50**
Add arterial management	$4	$3	-$0.1	$1	**$8**
Traveler information					
Traveler information	$18	$14	$0.7	$0.4	**$34**
Incident management					
Existing incident management	$50	$35	$2	$62	**$149**
Add improved incident management	$53	$38	$2	$38	**$131**

*May not equal the sum of benefit columns due to rounding.

Table 6.4 Incremental TMS Benefits for the I-405/I-5 Simulation Network (in $ million)

TMS Strategy	Travel Time	Vehicle Op. Costs	Emissions	Safety	Total*
Ramp metering					
Existing (simple adaptive with queue control)	$15	$28	$8	$40	**$92**
Change to corridor adaptive with queue control	$8	$9	$0.3	$1	**$18**
Traveler information					
Traveler information	$25	$20	-$0.4	$3	**$47**
Incident management					
Existing incident management	$19	$42	$18	$26	**$105**
Add Improved incident management	$4	$3	-$0.07	$13	**$20**

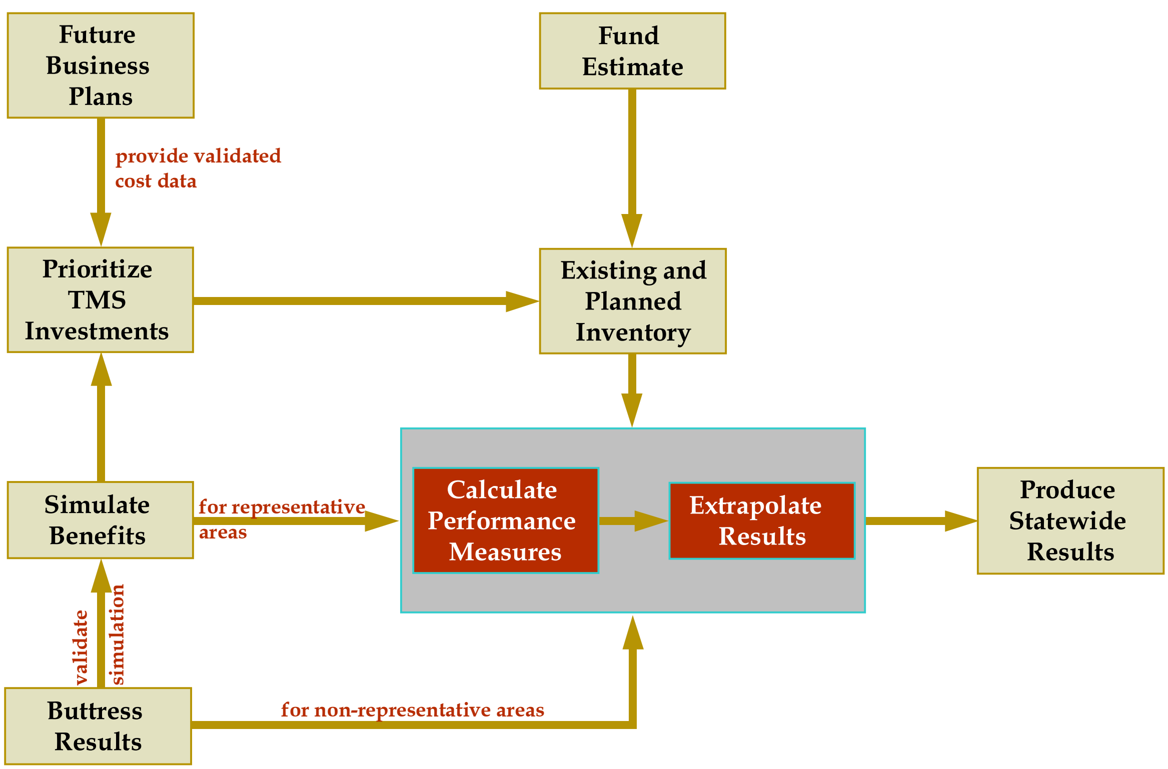
*May not equal the sum of benefit columns due to rounding.
**Includes existing TMS investments.

7.0 Extrapolation, Benefit-Cost Analysis, and TMS Deployment Plan

This section presents the methodology and results of conducting benefit-cost analysis and extrapolating findings statewide. These analyses were used to prioritize TMS investments, and derive the year-by-year expenditure plan for the deployment of TMS elements in California.

Figure 7.1 depicts the overall process for extrapolating TMS benefits statewide for TMS strategies. TMS benefits derived from the simulation and secondary research were used to prioritize TMS investments. Based on funding assumptions, the business plan recommendations were prioritized to develop a year-by-year existing and planned TMS inventory and expenditure plan. An overall benefit-cost ratio for the State was also estimated for TMS investments.

Figure 7.1 Overview of the TMS Benefits Extrapolation Process



7.1 Benefit Calculations

TMS benefits were extrapolated to other California freeway corridors using a combination of results from the micro-simulations and the secondary research. Expected improvements in travel speeds and traffic volumes were assigned based on attributes classifying similar freeway segments, including the following:

- Traffic volume;
- Number of lanes;
- Urban/rural designation; and
- Highway classification for each corridor.

Each step of the benefit-cost analysis included conservative assumptions to ensure that the results were defensible and achievable. As mentioned in Section 6.1, the Cal-B/C methodology considers only four primary user benefits and ignores other public benefits. The benefit-cost analysis for statewide TMS deployment does not include safety benefits, so that only three of the Cal-B/C benefits were considered. Table 7.1 summarizes the steps to conduct the analysis and conservative assumptions employed.

Table 7.1 Steps to Quantify TMS Benefits

Analysis Step	Conservative Assumptions
• Select two freeway corridors (I-680 in the Bay Area and I-405/I-5 in Orange County) for simulation	• Routes were selected to represent congested (I-680) and less congested routes (I-405/I-5), so that the benefits are not exaggerated.
• Calibrate base simulation models, simulate impacts resulting from TMS deployment, and estimate travel time and throughput benefits	• The analysis did not take into account TMS impacts on improving the reliability of travel time. National experience suggests that these benefits could be large.
• Quantify benefits of TMS strategies	• Safety benefits observed for ramp metering and incident management TMS processes were not taken into account. National experience suggests that these benefits could be large. • Some recommendations include investments in incident prevention, such as Highway Advisory Radio (HAR) and Regional Weather Information Systems (RWIS). Although the related costs were included, the benefits were not.
• Validate against real-world and reported results in California and the rest of the country	• Benefits were validated to be at the lowest range of observed and reported results.
• Extrapolate statewide results	• Only peak-hour benefits were included in the extrapolation, even though many of the congested routes already experience more than one hour of severe congestion.

Current and future highway travel speed and traffic volume information came from the ITMS, which provided corridor projections consistent with MPO travel forecasts. Existing highway accident rates came from Caltrans accident statistics.

Because ITMS data were not available for ramps or arterials statewide, benefits and dis-benefits for the ramps and arterials were assumed to be proportional to freeway benefits as illustrated in the micro-simulations for the I-680 and I-405/I-5 networks.

Benefits and costs were estimated over a 20-year life cycle for three types of user benefits, including travel time, vehicle operating costs, and emissions. Benefits for existing conditions (i.e., ramp metering, where it already existed and incident management) were subtracted from the estimated benefits to ensure that only incremental benefits were considered.

7.2 Cost Calculations

Costs for each scenario were provided by the TMS business plans. Separate business plans were developed for four TMS processes, including incident management, arterial signal management, traveler information, and ramp metering. A fifth business plan provided costs for traffic detection; freeway detection costs were allocated to the ramp metering business process, while arterial detection costs were allocated to the arterial signal management business process.

For freeway detection, ramp meters and adjacent detection costs were allocated to the simple adaptive ramp metering scenario. Additional mainline detection costs were allocated to the corridor-wide adaptive ramp metering scenario. Although detection costs were allocated to ramp metering, other TMS processes, especially the traveler information TMS process, rely heavily on detection. However, none of the costs were allocated to the other processes, since the investments are generally done specifically for ramp metering.

Once total statewide costs were derived from the business plans and the allocation process, they were further disaggregated to estimate costs for highway corridors. The Department provided an estimate of existing and needed field elements by corridor, which were used to estimate field element costs per corridor. Other costs, such as software development, planning, and system integration, were allocated proportionally to the corridors based on the total number of field elements.

For instance, the costs of new incident management software were allocated proportionally to the different corridors based on total number of changeable message signs and video cameras planned for each corridor. Similarly, the costs for the analysis and system development of ramp metering were allocated to corridors based on the total number of traffic monitoring stations needed for each corridor.

In the end, the costs for each scenario were estimated by corridor. As Caltrans and its partners develop more detailed corridor system management plans, these costs will need to be revised accordingly.

7.3 Statewide Benefit-Cost Results

The benefits derived from the simulations/secondary research/extrapolation process were compared to the costs contained in the business plans to develop a prioritization scheme for TMS implementation. This scheme was used to integrate the business action plans into a comprehensive TMS action plan.

7.3.1 Benefits-Cost Results by TMS Strategy

All benefit-cost ratios were calculated incrementally, representing the estimated incremental benefits divided by the incremental costs for each TMS strategy. The conclusions of the benefit-cost analysis can be summarized as follows:

- For all congested corridors that have no ramp metering currently, successful implementation of a **simple adaptive** ramp metering scheme provides the highest return on investment. Other, more sophisticated ramp metering strategies cannot be implemented before the investment in ramp meters and upstream detection is completed. The simple adaptive scheme can be the least restrictive form of ramp metering and can avoid ramp queue backups. It can do so by accelerating metering rates when ramps are backed up with vehicles. It may also be the most acceptable option to local agencies that are skeptical about the benefits of ramp metering. In this scheme, ramp meters and ramp detection equipment must be installed on the entire corridor. The benefit-cost ratio for this investment is 11 to 1. The total incremental life-cycle costs allocated to this strategy are approximately $270 million and the life-cycle benefits are estimated at almost $3 billion.

- For all congested corridors on which simple adaptive ramp metering has already been implemented, significant benefits could be achieved by **optimizing meter rates**, while continuing to avoid ramp backups. This requires Caltrans staff to analyze each ramp and set of ramps to derive the optimal metering rates and adjust their current configurations accordingly. This step does not require any incremental capital costs, although it does require significant research and analysis. The benefit-cost ratio for this strategy is close to 17 to 1. However, this strategy requires significant human resources to analyze and adjust ramp configuration rates continuously. Also, this strategy cannot be implemented before the simple adaptive ramp metering strategy is implemented first. The total incremental life-cycle costs allocated to this strategy are approximately $30 million and the life-cycle benefits are estimated to be almost $500 million.

- Only for severely congested corridors that already have simple adaptive ramp metering and optimized meter rates, additional incremental benefits can be achieved by implementing an **extended adaptive** scheme or, better yet, a **corridor adaptive ramp metering** scheme. Both require additional investment in detection over and beyond the detection required by the simple adaptive scheme. However, the associated benefits far exceed the costs if implemented correctly. Both algorithms can be configured to minimize backups on the ramps. The benefit-cost ratio for these investments is 13.5 to 1. They require additional investment in detection, but are very beneficial for corridors with multiple bottlenecks. The total incremental life-cycle cost allocated to this strategy is approximately $270 million and the life-cycle benefits are estimated to be more than

$3.5 billion. This strategy yields these types of benefits only on severely congested corridors.

- Implementing **advanced arterial signal actuation strategies** also provides benefits that exceed the associated costs. However, the highest benefits are achieved when state-controlled arterial signals are integrated with locally controlled arterial signals and freeway ramp meters. This requires significant coordination and software integration efforts on the part of the Department and its local partners. The benefit-cost ratio for the associated investments is 4.5 to 1, and requires additional investment in arterial detection. The total incremental life-cycle costs allocated to this strategy are approximately $120 million and the life-cycle benefits are estimated to be more than $550 million.

- Implementing **improved incident management** yields lower benefits than the other strategies. However, given that safety benefits were excluded from the benefit-cost analysis and that the additional field equipment related to these improvements also yield benefits related to traveler information, security preparedness, and AMBER alert implementation, it is still a valuable investment. Also, many benefits related to improved coordination, partnerships, communications, and training all provide additional benefits that are not included in this analysis. The benefit-cost ratio for the associated investments is approximately 3 to 1 and requires investments in closed-circuit televisions and changeable message signs. The total incremental life-cycle costs allocated to this strategy are approximately $1 billion and the life-cycle benefits are estimated to be almost $3 billion.

- Implementing **comprehensive traveler information** is only effective when the majority of a given region (e.g., county) is covered with detection, closed-circuit televisions, and changeable message signs. The additional costs for sharing data and developing tools to share information and travel options directly with the public are relatively small compared to the costs of deploying field elements. It is assumed that the benefits for traveler information are not achieved until appropriate field element deployments are completed. The benefits of this investment far exceed its costs (over 100 to 1), primarily because it builds on investments implemented by other TMS processes. However, it would require almost full coverage of field elements before the benefits can be achieved. The total incremental life-cycle cost allocated to this strategy is approximately $20 million and the life-cycle benefits are estimated to be more than $2 billion.

7.3.2 Aggregate Benefit-Cost Results

If an aggressive TMS funding scheme of $150 million per year were assumed, full implementation of the TMS action plan would take 10 years starting in 2003. As described in Section 7.4, implementation would take approximately 24 years under current TMS funding levels of $50 million per year.

Both funding scenarios yield a total benefit-cost ratio of 7.5 to 1. Figure 7.2 presents the distribution of these benefits by category. Safety benefits were not included and benefits were counted for only the peak hour of travel.

Figure 7.2 Distribution of TMS Life-Cycle Benefits

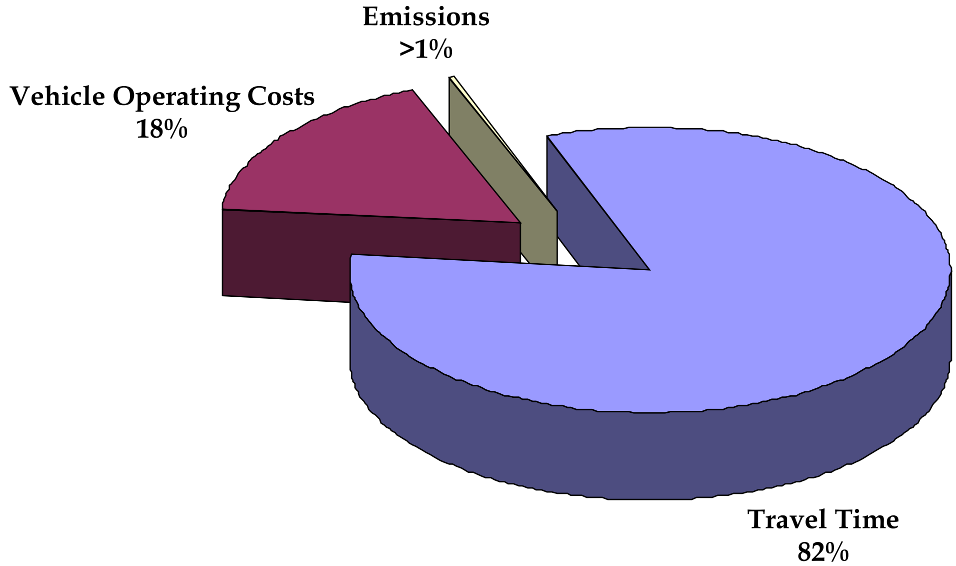


Figure 7.3 shows the annual non-discounted capital expenditures and benefits. Capital investments are completed after 10 years, while benefits continue through the full 20-year period.

Figure 7.3 Cumulative TMS Benefits

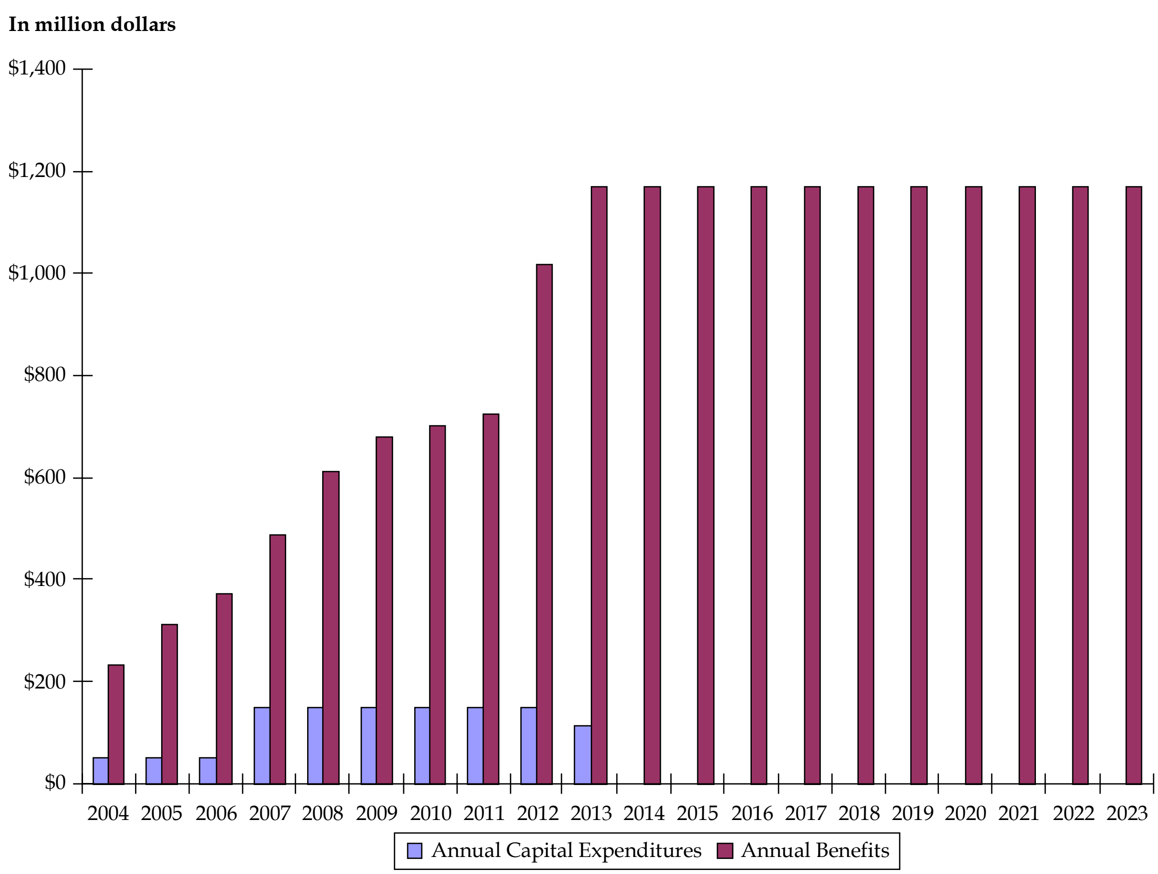
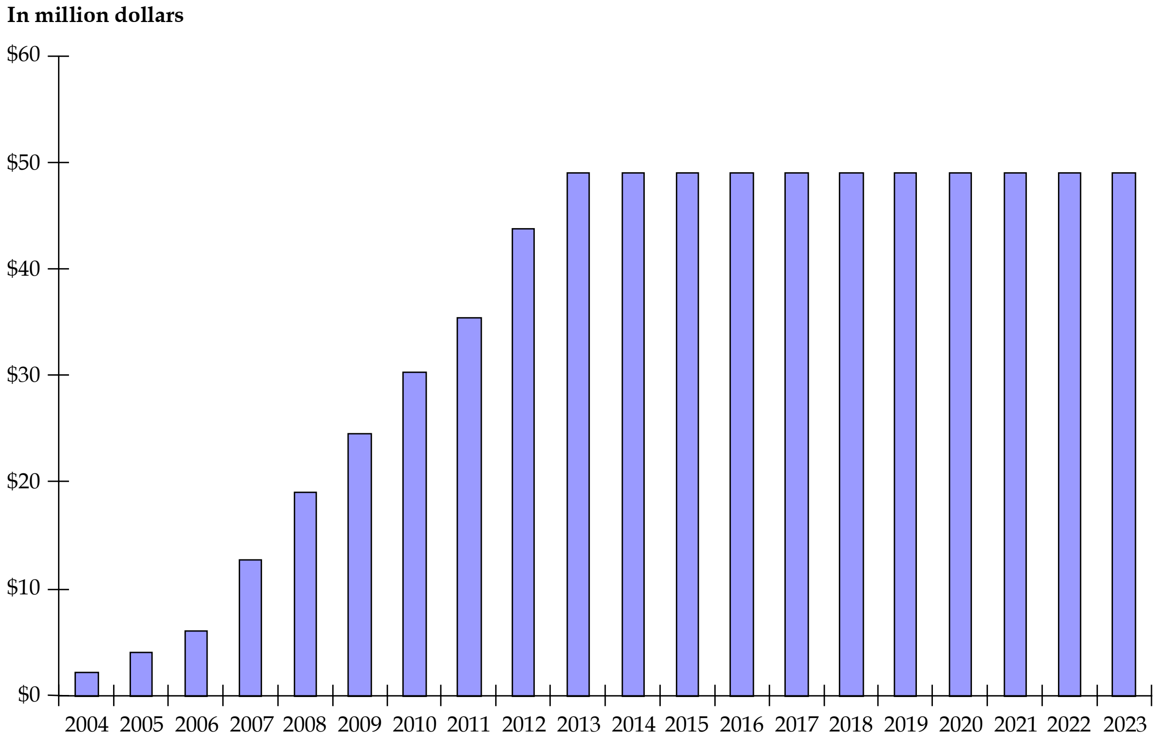


Figure 7.4 shows the incremental, non-discounted annual operations and maintenance costs over the same time period. These costs include replacement costs for the field elements and continue over the full 20 years. Since replacement costs are included, the benefits of TMS are expected to extend even beyond the time horizon of Figure 7.3 without additional capital expenditures.

Figure 7.4 Cumulative Annual TMS Operating and Maintenance Costs



■ 7.4 TMS Deployment Plan

A year-by-year inventory and deployment plan for existing and planned field elements was developed based on the statewide benefit-cost analysis and the phased action plan. Although the benefit-costs of various TMS strategies strongly influenced the phasing of field element deployment, the year-by-year deployment plan was not developed strictly using benefit-cost ratios. Several other factors were taken into consideration, including pragmatic deployment capabilities, non-quantified benefits, as well as analysis and integration requirements.

The Financial Plan considered the following two separate funding scenarios defined by Caltrans for TMS implementation:

1. **No changes in existing funding –** Approximately $50 million per year is currently being expended on TMS-only projects on the State Highway System; and

2. **Accelerated funding –** Approximately $150 million per year is required to complete implementation of the TMS Master Plan within a 10-year horizon.

The two funding scenarios yield the same benefits and require the same costs. The only difference is that the accelerated funding scenario allows TMS implementation to be completed in 10 years and, thus, benefits are achieved sooner. With no changes in existing funding, TMS implementation would require 24 years before deployment is complete. Given the lengthy time horizon for the existing funding scenario, the year-by-year deployment plan was developed based on the accelerated funding scenario. The next sections describe the development of the two funding scenarios, present the year-by-year deployment plan, and the phasing of benefits and costs.

7.4.1 Development of Funding Scenarios

The existing and accelerated funding scenarios were defined based on a review of funding for current TMS elements and other likely funding sources. Most TMS funding comes from the State Highway Operating and Protection Program (SHOPP) Transportation Management 315 Program. Some TMS projects have been funded using other federal, state, and local sources, so the State Transportation Improvement Program (STIP) was also examined.

The analysis was based on budget data from the California Transportation Improvement Program System (CTIPS). CTIPS is a project programming database developed by Caltrans to manage transportation programming documents required under state and federal law. CTIPS is intended to streamline the programming process, foster communication between agencies, and eliminate redundant data entry errors. Each programming agency is responsible for entering data into the CTIPS database. Caltrans provides information on the SHOPP, the ITIP portion of the STIP, as well as rural STIP projects. Regional agencies enter information about Regional Transportation Improvement Program (RTIP) projects.

In order to develop the TMS funding scenarios, CTIPS provided information for the 2002 STIP and SHOPP. In both cases, projects from the current official document were used. For the SHOPP, only projects with a 315 (Transportation Management System) funding code were examined. For the STIP, projects were identified using the following two primary methods:

1. **Specific program codes –** Several programs were considered, including Transportation System Management (TSM) Local Transportation Demand Management, TMS Local City Street Improvements, and SHOPP Funds on STIP Projects; and

2. **Project titles containing certain key words –** Project titles were searched using 31 TMS-related terms, such as "monitoring," "loop," "fiber," and "ATMS."

The searches resulted in 73 TMS-related projects on the State Highway System, as well as local streets and roads. These projects fell into the following three categories:

1. **State –** Forty-nine projects occurring on the State Highway System totaling approximately $201 million over the four-year funding period. The funding total excludes four projects for which separate TMS expenditures from total funding were not identified.

2. **Local –** Nineteen TMS-related projects, such as fiber optics, closed-circuit television cameras, and automated traffic surveillance and control, were identified. Total spending on these projects is $58 million over the four-year funding period.

3. **Signal Coordination:** Six projects occurring on local streets and roads to improve signal timing or to create signal interconnects were identified. Total funding is $33 million over the four-year period.

Among the 49 State Highway projects, most (38) were funded through the SHOPP 315 program, which provides approximately $171 million in programmed projects over the next four year. This equals just under $45 million per year.

The remaining 11 projects used a combination of federal, state, and local sources, such as local Surface Transportation Program (STP local), Congestion Mitigation and Air Quality (CMAQ), Regional Improvement Program (RIP), Traffic Congestion Relief Program (TCRP), and local sales taxes. Most of these 11 projects either included TMS investment as part of a much larger capital project (e.g., adding HOV lanes) or occurred in District 11, where SANDAG has contributed RIP money towards TMS investments on the State Highway System.

As a result of this analysis, the following two scenarios were defined for TMS implementation:

1. **No change in existing funding –** The approximately $50 million per year currently being expended on TMS-only projects on the State Highway System; and

2. **Accelerated funding –** Approximately $150 million per year required to complete implementation of the TMS Master Plan within 10 years.

7.4.2 Year-by-Year TMS Deployment Plan

A year-by-year TMS deployment plan was developed using the accelerated funding scenario. The plan (shown in Table 7.2) includes several of the following field elements:

- Ramp meters;
- Traffic monitoring stations;
- Changeable message signs;
- Video cameras;
- Highway advisory radio;

- Roadway weather information systems; and
- Arterial mid-block traffic monitoring stations.

The deployment of these elements was estimated based on the statewide benefit-cost analysis and the phased action plan. However, several factors in addition to the benefit-cost of different TMS strategies were taken into consideration in the following deployment phasing:

- **Pragmatic deployment capabilities –** The deployment considered Caltrans' ability to deploy a large number of field elements and the potential disruption to traffic. For instance, even though ramp metering strategies were found to have higher benefit-cost ratios than arterial management strategies, it was deemed prohibitive to install thousands of traffic monitoring stations in a short time period. Each installation would require closing lanes and disrupting traffic for a period of time. There is also a limitation on how many installations current Caltrans staff can oversee and manage. The same applies to the installation of ramp meters. As a result, the highest number of traffic monitoring stations or ramp meters estimated to be installed in one year is less than 500.

- **Non-quantified benefits –** Incident management strategies yielded a lower benefit-cost ratio than other strategies in the simulations. However, these strategies generate additional safety benefits that were excluded in order to provide a conservative benefit-cost analysis. AMBER alert and security preparedness benefits were also not counted. Since these benefits were not considered, some field elements related to incident management were allocated for deployment in the early years of TMS Master Plan implementation.

- **Analysis and integration requirements –** Some arterial management strategies call for deployment of mid-block traffic monitoring stations and integration of arterial management and ramp metering systems. These types of efforts take time and require significant analysis and testing. As a result, related field elements were phased to allow the Department and its partners time to study, analyze, and test the different action items. Field elements necessary for implementing corridor-wide adaptive ramp metering strategies were phased in a similar manner. Candidate corridors for these strategies require significant analysis and study. The State cannot implement these strategies on too many corridors in the same year.

The results of this phasing effort show a general (although not exclusive) focus on investments in ramp meters and traffic monitoring stations in congested corridors for the first five years of TMS implementation, followed by a focus on arterial mid-block traffic monitoring stations and incident management field elements. Additional traffic monitoring stations and ramp meters for less congested corridors, as well as traffic monitoring stations for non-congested corridors, are deployed at the end of the phasing.

Table 7.2 shows an annual total number of TMS field elements by type in the phased deployment given accelerated funding. This deployment would be spread over 24 years under existing funding.

Table 7.2 Year-by-year TMS Deployment Plan by Field Element Type

Field Element	Existing	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Freeway ramp meters	1,956	2,139	2,254	2,365	2,797	3,083	3,231	3,450	3,548	3,726	3,928
Traffic monitoring stations	1,457	1,697	1,877	2,053	2,488	2,908	3,138	3,526	3,820	4,179	4,632
Changeable message signs	509	517	532	545	560	586	603	649	662	916	1,171
Video cameras	1,045	1,060	1,083	1,107	1,173	1,286	1,425	1,503	1,791	2,384	3,196
Highway advisory radio	117	119	126	139	145	162	183	233	271	324	324
Roadway weather information system	66	66	66	73	77	83	113	152	198	262	262
Arterial mid-block traffic monitoring stations	0	69	139	286	986	1,575	2,051	2,381	2,381	2,500	2,500